

Table of Contents

1. Introduction	2
2. An Overview of the Principles of Transmission over Optical Fiber	3
• Construction	3
• Reflection and refraction	3
• Signaling	4
• Requirements for reliable transmission	5
3. Testing Theory – Performance of Optical Fiber Cabling	12
• Industry performance standards	12
• Cabling certification	16
4. Fiber Verification Testing	25
5. How to Certify Fiber Optic Cabling with OLTS and LSPM	26
6. How to Certify Fiber Optic Cabling with an OTDR	32
• Cable certification test strategy	36
7. Common Faults	37
8. How to Troubleshoot Common Faults with an OTDR	39
• Finding faults with an OTDR	39
9. End-Face Inspection and Cleaning	44
• Inspection	44
• Cleaning	45
10. Conclusion	46
11. Glossary	47
12. Appendices	48

1. Introduction

As fiber links support higher speed network bandwidths with increasingly stringent requirements, it is becoming all the more important to ensure that your backbone links meet tightening loss standards. The need for higher data transmission capacity continues to grow as network applications grow and expand. These higher transmission speeds demand cabling that delivers higher bandwidth support. This testing guide outlines cabling performance requirements, field testing, certification and troubleshooting techniques and instruments to ensure that the installed optical fiber cabling supports the high data rate applications such as 1 and 10 Gigabit per second (Gbps) Ethernet, Fibre Channel and the anticipated 40 and 100 Gbps Ethernet applications.

A local area network (LAN) or an enterprise ("premises") network connects users up to a distance of 2 to 5 km. It encompasses the intra-building connectivity as well as inter-building cabling or the campus cabling. Optical fiber cabling is primarily used for longer distance, higher bandwidth connectivity while twisted pair copper cabling typically provides the connection to the end-user or to the edge devices. This copper cabling can support network connectivity to a distance of 100 meters (328 feet). Optical fiber cabling is the preferred medium for distances beyond 100 meter such as riser cables in the building.

This booklet reviews best practices for test and troubleshooting methods as well as the test tools to ensure that installed Optical Fiber cabling provides the transmission capability to reliably support LAN or enterprise network applications. "Certification," or the process of testing the transmission performance of an installed cabling system to a specified standard, ensures a quality installation. It also provides official documentation and proof that the requirements set by various standards committees are fully satisfied.

Fiber optics is a reliable and cost effective transmission medium, but due to the need for precise alignment of very small fibers, problems ranging from end-face contamination to link damage can occur. Regardless, narrowing down the source(s) of failure is often a time-consuming and resource-intensive task.

For this reason, Fluke Networks has created an enterprise-focused fiber troubleshooting guide to assist in ensuring: 1) proper assessment of cable installation quality, and 2) efficient troubleshooting to reduce the time spent identifying the root cause of a problem before taking corrective action to fix it. Note that this guide does not address issues that are especially germane to the long-haul telecommunications application of the fiber optics technology.

2. An Overview of the Principles of Transmission over Optical Fiber

Construction

Optical fiber cable consists of extremely thin strands of ultra-pure glass designed to transmit light signals. **Figure 1** depicts the construction of the buffered glass strand that is the basic component in many optical fiber cable constructions. The center of the fiber strand is called the 'core'. The core actually contains the light signals to be transmitted. A glass layer called the 'cladding' surrounds the core. The cladding confines the light in the core. The outer region of the optical fiber is the coating or 'buffer'. The buffer, typically a plastic material, provides protection and preserves the strength of the glass fiber.

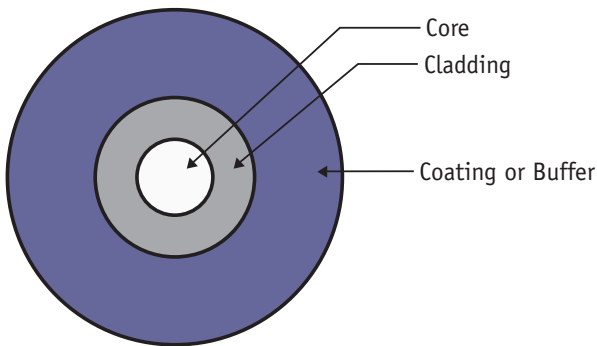


Figure 1 – Cross section of an optical fiber

A common outer diameter for the cladding is 125 micron (μm) or 0.125 mm. The diameter of the core for optical fiber cable commonly used in premises infrastructures is either 62.5, 50 or 9 μm . The larger 62.5 and 50 μm diameter defines multimode fiber types; singlemode fiber has the smaller diameter with a nominal value of 9 μm .

Reflection and refraction

The operation of optical fiber is based on the principle of total internal reflection.

Figure 2 illustrates this principle when light travels from air into water. When light arrives at the water surface at an incident angle θ less than the critical angle θ_c , it travels into the water but changes direction at the boundary between air and water (*refraction*). When a light beam strikes the water surface at an angle greater than the critical angle, the light reflects on the water surface. Each material is characterized by an index of refraction, which is represented by the symbol n . This index, also called refractive index, is the ratio of the velocity of light in vacuum (c) to its velocity in a specific medium (v).

$$n=c/v$$

The refractive index in vacuum (outer space) is 1 ($v = c$). The refractive index for air (n_a) is 1.003 or slightly higher than that of a vacuum while the refractive index for water is 1.333. A higher value of the refractive index n of a material indicates that the light travels slower in that material. Light travels faster through the air than in water.

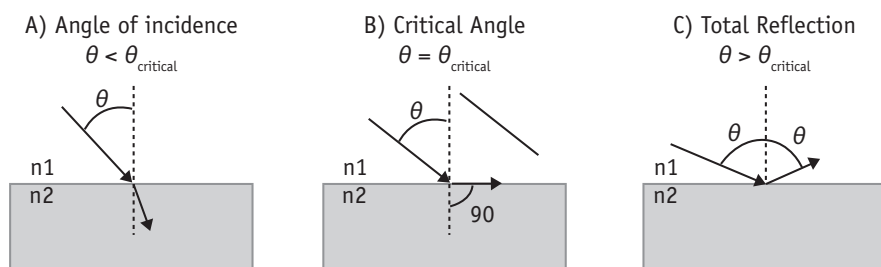


Figure 2 - Principle of total reflection

The core of an optical fiber has a higher refractive index than the cladding. The light that strikes the boundary between the core and the cladding at an incident angle greater than the critical angle reflects and continues to travel within the core. This principle of total reflection is the basis for the operation of optical fiber. The critical angle is a function of the refractive index of the two media, in this case the glass in the core and the glass in the cladding. The refractive index for the core typically is around 1.47 while the refractive index for the cladding is approximately 1.45.

Because of this principle, we can describe an imaginary cone with an angle α which is related to the critical angle (see **Figure 3**). If the light is launched into the fiber end from within this cone, it is subject to total reflection and travels in the core. The notion of this cone is related to the term numerical aperture, the light gathering ability of the fiber. Light launched into the fiber end outside of this cone will refract into the cladding when it meets the core-cladding boundary; it does not stay within the core.

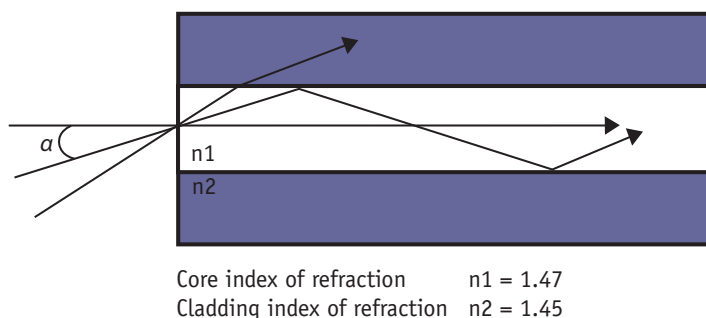


Figure 3 - Numerical aperture and total reflection: Light that enters the fiber within an angle α travels in the core

Signaling

Local area networks like Ethernet and Fibre Channel transmit pulses that represent digital information. The *bit* – short for binary digit – is the basic unit of digital information. This unit can only take one of two values: 0 or 1. Numeric data is transformed into a digital number. Other data such as characters are coded in a string of bits. An 'On' or an 'Off'

state electronically represents the value of a bit. Similarly, a serial string of light pulses represents the digital information transmitted over an optical fiber link. The 'On' state represents a bit with value 1 and the 'Off' state represents a bit with value 0. **Figure 4** represents such a sample of digital information as transmitted over an optical fiber cable.

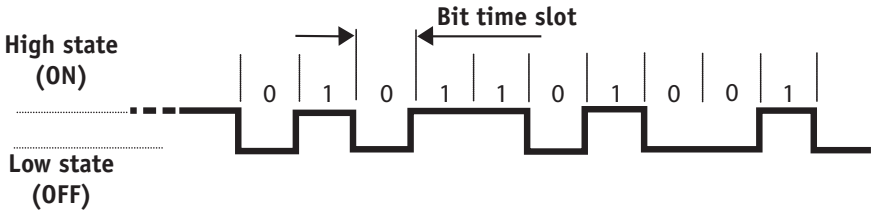


Figure 4 - A typical pulse train that represents the digital data

The representation of the pulses in **Figure 4** is "idealized". In the real world, pulses have limited rise and fall times. **Figure 5** describes the main characteristics of a pulse. Rise time indicates the amount of time required to turn the light to the 'On' state; it is typically characterized by the time required to transition from 10% to 90% of the amplitude. Fall time is the opposite of rise time and represents the duration to turn the light from 'On' to 'Off'. Rise time and fall time are critical parameters; they determine the upper limit for the rate at which the system can create and transmit pulses.

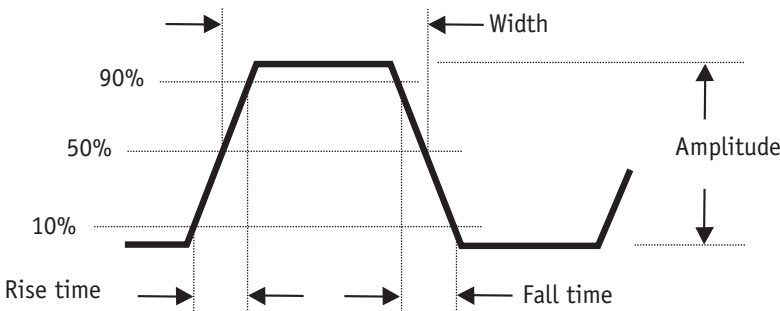


Figure 5 - Analysis of a pulse

When transmitting one billion or more bits per second (data rate of 1 Gbps or more), LED light sources can no longer be used due to the rise and fall time of the LED light sources. These higher-speed systems only use laser light sources. A very common light source in premises networks is the VCSEL (Vertical Cavity Surface Emitting Laser) that transmits light at the 850 nm wavelength.

Requirements for reliable transmission

When the light source in the transmitting device generates a pulse train like the one depicted in **Figure 4**, the optical fiber link must transmit this pulse train with sufficient signal fidelity so that the detector at the receiving device can detect each pulse with its true value of 'On' or 'Off'.

Minimally, two things are required to ensure reliable reception and transmission:

Channel insertion loss: the maximum signal loss or signal attenuation allowed over the transmission medium from the transmitting device to the receiving device. The term 'channel' defines the end-to-end transmission medium between transmitter and receiver. The signal loss consists of the cumulative losses in the optical fiber cabling and in each connection or splice.

Signal dispersion: As we will discuss, the light pulses have a tendency to spread out as they are traveling along the fiber optical link due to dispersion. The spreading must be limited to prevent the pulses from running together or overlapping at the receiving end. Both of these parameters – channel loss and signal dispersion – play a critical role in establishing reliable and error-free transmission. Dispersion cannot be measured in the field. The network standards define a maximum channel length for an optical fiber channel; the maximum length is a function of data rate and the bandwidth rating of the optical fiber. The bandwidth rating, in turn, is based on laboratory measurements to characterize the modal dispersion in multimode optical fibers.

Loss

Loss or attenuation has been a well-established performance parameter in the cabling and network application standards. The signal must arrive at the end of the fiber optic link – the input to the detector at the receiving device – with sufficient strength to be properly detected and decoded. If the detector cannot clearly “see” the signal, transmission certainly has failed.

Attenuation or signal loss in optical fiber is caused by several intrinsic and extrinsic factors. Two intrinsic factors are scattering and absorption. The most common form of scattering, called 'Rayleigh Scattering', is caused by microscopic non-uniformities in the optical fiber. These non-uniformities cause rays of light to partially scatter as they travel along the fiber core and thus some light energy is lost. Rayleigh scattering is responsible for roughly 90% of the intrinsic loss in modern optical fibers. It has a greater influence when the size of the impurities in the glass is comparable to the wavelength of the light. Longer wavelengths are therefore less affected than shorter wavelengths and longer wavelengths are subject to less loss than the shorter wavelengths.

Extrinsic causes of attenuation include cabling manufacturing stresses and bends in the fiber. Bends can be distinguished in two categories: microbending and macrobending. Microbending is caused by microscopic imperfections in the geometry of the fiber resulting from the manufacturing process such as rotational asymmetry, minor changes in the core diameter, or rough boundaries between the core and cladding. Mechanical stress, tension, pressure or twisting of the fiber can also cause microbending. **Figure 6** depicts microbending in a fiber and its effect on the light path.

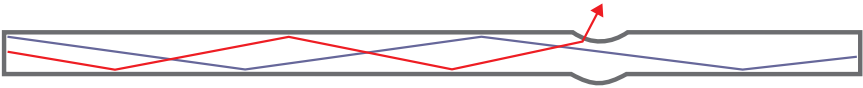


Figure 6 – A microbend in an optical fiber causes some light to escape the core which adds to the signal loss

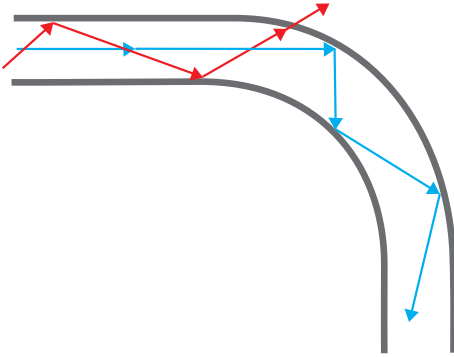


Figure 7 – A macrobend or bend with a tight bending radius cause higher order mode light to escape from the multimode core and thus cause signal loss.

The primary cause of macrobending is a curvature with a small radius. The standards describe the bend radius limits as follows: “Cables with four or fewer fibers intended for Cabling Subsystem 1 (horizontal or centralized cabling) shall support a bend radius of 25 mm (1 in) when not subject to tensile load. Cables with four or fewer fibers intended to be pulled through pathways during installation shall support a bend radius of 50 mm (2 in) under a pull load of 220 N (50 lbf). All other optical fiber

cables shall support a bend radius of 10 times the cable outside diameter when not subject to tensile load, and 20 times the cable outside diameter when subject to tensile loading up to the cable’s rated limit.”

Figure 7 shows the effect of a bend with smaller radius on the path of the light in the fiber. Some light in the higher order mode groups is no longer reflected and guided within the core.

The length of the fiber and the wavelength of the light traveling through the fiber primarily determine the amount of attenuation. The loss in an installed optical fiber link consists of the loss in the fiber plus the loss in connections and splices. The losses in connections and splices represent the majority of the losses in shorter fiber optical links typical in the premises network application. A troubleshooting tool like an Optical Time Domain Reflectometer (OTDR) will allow you to gauge and inspect the loss at each connection or splice.

Dispersion

Dispersion describes the spreading of the light pulses as they travel along the optical fiber. Dispersion limits the bandwidth of the fiber, thereby reducing the amount of data the fiber can transmit. We will limit the discussion of dispersion to modal dispersion in multimode fiber.

The term ‘multimode’ refers to the fact that numerous modes of light rays propagate simultaneously through the core. **Figure 8** shows how the principle of total internal reflection applies to multimode step index optical fiber. The term ‘step index’ refers to the fact that

the refractive index of the core is a step above the index of the cladding. When the light enters the fiber, it separates in different paths known as 'modes'. The principle of total internal reflection described above and shown in **Figure 3** guides each path or mode through the fiber core. One mode travels straight down the center of the fiber. Other modes travel at different angles and bounce back and forth due to the internal reflection. The modes bouncing the most are called the 'higher order modes'. The modes bouncing very little are the 'lower order modes'. The shortest path is the straight line. All other paths taken by the light (modes) are longer than the straight line path – the steeper the angle, the more bounces taken, and the longer the path traveled. As the path length varies, so varies the travel time to reach the end of the fiber link. The disparity between arrival times of the different light rays also known as differential mode delay (DMD), is the reason for dispersion or spreading of the light pulse as it travels along the fiber link.

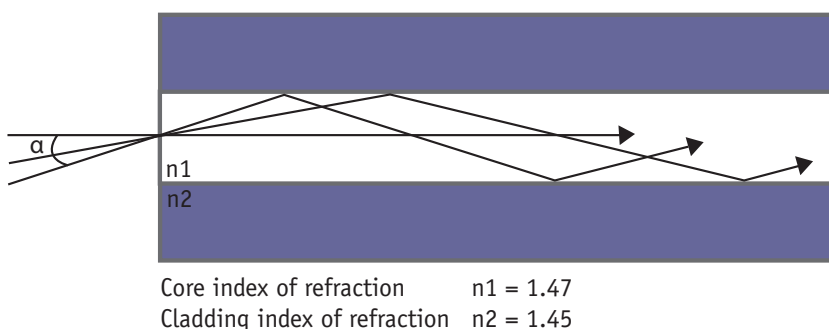


Figure 8 – The optical fiber gathers all the light that enters within the angle determined by the Numerical Aperture. The light reflects at the boundary between the core and the cladding and travels along different paths. A path is also called a mode. Multimode optical fiber guides the light along multiple paths or modes. The light that enters at the wider angle takes more bounces and travels a longer way. It represents the higher order modes.

The effect of dispersion increases with the length of the optical fiber link. As pulses travel farther, the difference in the path length increases, therefore the difference in arrival times increases and the spreading of the pulses continues to grow. The effect is that the light pulses arriving at the end of the longer fiber link run into each other and that the receiver can no longer distinguish them, let alone decode their state (value). Higher data rates are achieved by sending shorter pulses at rapid succession. Dispersion limits the rate at which pulses can be transmitted. In other words, dispersion limits the bandwidth of the cabling.



Figure 9 – The net effect of dispersion causes the transmitted pulses to run together and overlap at the end of the link (input to the detector). The detector can no longer recognize and decode the state of individual pulses.

To compensate for the dispersion inherent in multimode step index fiber, multimode graded index fiber was developed. ‘Graded index’ refers to the fact that the refractive index of the core gradually decreases farther away from the center of the core. The glass in the center of the core has the highest refractive index which causes the light in the center of the core to travel at the slowest speed. The light that takes the shorter path through the fiber is traveling at a slower speed. This core construction allows all the light rays to reach the receiving end in approximately the same time, reducing the modal dispersion in the fiber. As **Figure 10** depicts, the light in graded index multimode fiber no longer travels in straight lines from edge to edge but follows a serpentine path; it is gradually reflected back toward the center of the core by the continuously declining refractive index of the glass in the core.

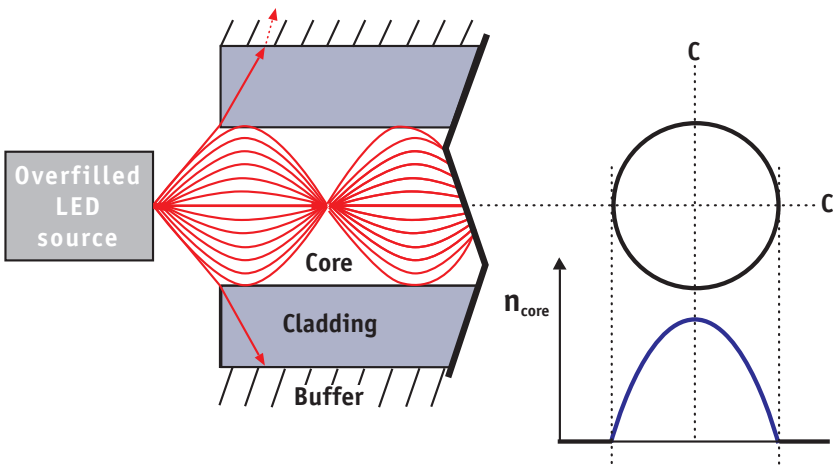


Figure 10 – Graded index multimode fiber. The refraction index of the core changes throughout the core. It is highest in the center and gradually decreases toward the boundary with the cladding. This creates light paths (modes) that follow a serpentine path as shown in the left panel of this figure. The lower modes light (center of the core) travels slowest while the modes in the outer regions that travel the longer distances travel faster. Graded index multimode fiber therefore provides better bandwidth.

Laser-optimized multimode fiber that is to be used for the newer high-speed network application (data rates in the Gigabit per second range) is constructed as graded index multimode fiber. This laser-optimized multimode fiber also uses the smaller 50 μm core diameter. The smaller core diameter also decreases the dispersion effect in the fiber by limiting the number of modes.

‘Singlemode’ fiber, as the name implies, only allows one mode of propagation at wavelengths longer than the cutoff wavelength¹. The 1310 nm wavelength that is used by most premises network application over singlemode fiber (9 μm core diameter) is well above the cutoff wavelength which is between 1150 nm and 1200 nm. Singlemode fibers using the longer wavelengths retain the fidelity of each light pulse over longer distances since they exhibit no modal dispersion (caused by multiple modes). Thus, more information can

¹ **Cutoff Wavelength:** The wavelength below which a singlemode optical fiber ceases to transmit in a singlemode.

be transmitted per unit of time over longer distances (intrinsic loss is less at the higher wavelengths). This gives singlemode fibers higher bandwidth compared to multimode fiber.

Singlemode fiber design has evolved over time as well. Other dispersion mechanisms and non-linearities exist which we will not cover since they play a much less important role in the optical fiber application in premises networks. Singlemode fiber has some disadvantages. The smaller core diameter makes coupling light into the core more difficult. The tolerances for singlemode connectors and splices are more demanding to achieve good alignment of the smaller core. Furthermore, the longer wavelength laser light sources are more expensive than the VCSEL operating at 850 nm.

Bandwidth

A key fiber performance characteristic is bandwidth, or information-carrying capacity of the optical fiber. In digital terms, bandwidth is expressed in a bit rate at which signals can be sent a given distance without one bit interfering with the bit before it or following it. Bandwidth is expressed in the product MHz•km. The interference occurs because of the dispersion phenomenon we discussed above.

Bandwidth can be defined and measured in a variety of ways. The three standardized bandwidth specifications and applicable measurements are Overfilled Bandwidth, Restricted Modal Bandwidth and Laser Bandwidth or Effective Modal Bandwidth (EMB). The reason for these different methods stems from the differences in the characteristics of the light sources used to transmit information.

The traditional light source for 10 Mbps and 100 Mbps Ethernet has been the Light Emitting Diode (LED), an excellent option for applications operating up to speeds of 622 Mbps. LEDs produce a uniform light output that fills the entire core of the optical fiber and excites all of its modes. To best predict the bandwidth of conventional multimode fibers when used with LED light sources, the industry uses a method called Overfilled Bandwidth (OFL).

As mentioned above, LEDs cannot be modulated fast enough to transmit the one billion or more pulses per second required for Gbps data rates. A common light source to support the gigabit transmission speeds in premises network applications is the VCSEL (Vertical Cavity Surface Emitting Laser) at 850 μm wavelength. Unlike an LED, the light output of a VCSEL is not uniform. It changes from VCSEL to VCSEL across the end-face of the optical fiber. As a result, lasers do not excite all the modes in multimode fiber but rather a restricted set of modes. And what may be more important, each laser fills a different set of modes in the fiber and with differing amounts of power in each mode.

A superior method of ensuring bandwidth in optical fiber links for the deployment of Gigabit speeds is the measurement of DMD (differential mode delay – see the prior discussion

on dispersion). This measurement technique is the only bandwidth specification mentioned in the standards for 10 Gbps data rates. The Laser Bandwidth or EMB is mathematically derived from the DMD measurements.

Fiber Types

The ISO/IEC standard (std) 11801 defines four types of optical fibers to support various classes of premises network applications. The ISO/IEC std 11801 or std 24702 defines three multimode optical fiber types (OM1, OM2 and OM3) and two singlemode types (OS1 and OS2). These type designations are finding acceptance in the North American market as well and are listed in the TIA-568-C.3 document². The following table provides a short overview of the main characteristics of these fiber types.

		Cable attenuation coefficient (dB/km)		Minimum modal bandwidth (MHz•km)		
				Overfilled	Laser	
Wavelength (nm)		850	1300	850	1300	850
Optical fiber type	Core diameter (µm)					
OM1	50 or 62.5	3.5	1.5	200	500	Not specified
OM2	50 or 62.5	3.5	1.5	500	500	Not specified
OM3	50	3.5	1.5	1,500	500	2,000
OM4 (proposed)	50	3.5	1.5			To be determined 3,500 - 4,700

Table 1 – Multimode optical fiber types

Note that older or legacy multimode fibers with an overfilled bandwidth rating below 200 MHz•km are not included in this table and are no longer recommended in the design of any new installations. The OM3 designation describes the high-bandwidth laser-optimized multimode optical fiber cable. Among the different fiber optic based transmission standards for 10 Gbps Ethernet, 10GBASE-SR (the serial transmission of 10 Gigabits per second using the short wavelength VCSEL [850nm]) is the most economical implementation of this high-speed network application in the premises local area network, the datacenter or the storage area network. And for this application, OM3 is the preferred fiber optic cable type.

Manufacturers of optical fiber have developed laser optimized multimode fiber with modal bandwidth characteristics that are better than the OM3 type specifications. This may lead to the adoption of an 'OM4' rating with a proposed effective laser bandwidth in the range from 3,500 to 4,700 MHz•km.

OS2 is commonly referred to as "low water peak" singlemode fiber and is characterized by having a low attenuation coefficient near 1383 nm.

² Telecommunications Industry Association (TIA). TIA represents the telecommunication industry in association with the Electronic Industries Association. TIA is accredited by the American National Standards Institute (ANSI) as a major contributor to voluntary standards. Standard ANSI/EIA/TIA 568 Commercial Building Telecommunications Cabling Standard is the primary standard related to structured cabling systems in North America.

3. Testing Theory – Performance of Optical Fiber Cabling

Certification is the most complete form of field-testing. As alluded to earlier, the certification test procedure ensures that the installed cabling conforms to the transmission performance standards defined in the industry standards such as the applicable International Organization for Standard/International Electrotechnical Commission (ISO/IEC) and TIA standards.

Industry performance standards

Two groups of standards should be considered to obtain a complete specification and ensure that the installed cabling will support the requirements for the intended network applications. The goal of certification testing after all is to gain the confidence that the cabling system will not be the source of any network malfunction even before the network equipment is installed. The two groups of standards recognize each other's requirements but do not provide a perfect overlap.

Generic installation standards

The generic standards address the general installation rules and performance specifications. The applicable standards are the ISO std 11801:2002 and ISO/IEC 14763-3, Information Technology – Implementation and operation of customer premises cabling – Testing of optical fibre cabling, and the ANSI/TIA 568 C. The latter – revision 'C' – consists of four volumes. Volume C.0 Generic Telecommunications Cabling for Customer Premises provides a general overview. Volume C.1 Commercial Building Telecommunications Cabling Systems describes the recommended design for commercial buildings and volumes C.2 and C.3 describe the performance specifications for the cabling components; C.2 addresses twisted pair balanced cabling and volume C.3 optical fiber cabling.

These standards address field-test specifications for post-installation transmission performance which depends on cable characteristics, length, connecting hardware, cords, cross-connect wiring, the total number of connections, and the care with which they are installed and maintained. For example, severe cable bends, poorly installed connectors and a very common problem – the presence of dust, dirt and other contaminants on the end-face of fibers in connections – negatively influence link attenuation.

The installation standards specify as a minimum transmission performance that the measured link loss be less than the allowed maximum (loss limit), which is based on the number of connections, splices and the total length of optical fiber cable. This certification must be executed with an accurate Optical Loss Test Set (OLTS) or a Light Source and Power Meter (LSPM). These test tools will be described in more detail later as well as the Optical Time Domain Reflectometer (OTDR). An OTDR provides a good indication of total link loss but is not sufficiently accurate for link loss certification testing. Certification

includes the requirement of documentation of the test results; this documentation provides the information that demonstrates the acceptability of the cabling system or support of specific networking technologies.

The link attenuation allowance calculation:

Link Attenuation Allowance (dB) = Cable Attenuation Allowance (dB) + Connector Insertion Loss Allowance (dB) + Splice Insertion Loss Allowance (dB)

Where:

Cable Attenuation Allowance (dB) = Maximum Cable Attenuation Coefficient (dB/km) × Length (km)

Connector Insertion Loss Allowance (dB) = Number of Connector Pairs × Connector Loss Allowance (dB)

Splice Insertion Loss Allowance (dB) = Number of Splices × Splice Loss Allowance (dB)

Table 1 lists the cable attenuation coefficient by cable type; this coefficient is 3.5 dB/km for all multimode optical fiber types recommended for premises cabling systems. Indoor rated singlemode fiber has an attenuation coefficient of 1.5 dB/km while outdoor rated singlemode fiber has a coefficient of 1 dB/km or lower. The standards also specify the maximum connector loss allowance as 0.75 dB and the maximum splice loss allowance as 0.3 dB. Well-executed cabling installations should generally deliver connections that exhibit significantly lower connection losses. The same statement applies to splice losses. Note that the length of the fiber link must be known or must be measured by the test tool to determine the loss limit.

Table 2 shows an example application of the loss limit calculations. The calculation is performed for a 300 m OM3 fiber link segment with just two end connectors and no splices that is used with an 850 nm light source.

	Max. loss per unit length or per item	Length/ number	Calculated loss (dB)
Max. loss in fiber	3.5 dB/km	0.3	1.05
Max. loss in connections	0.75 dB	2	1.5
Max. loss in splices	0.3 dB	0	0.0
Link loss limit			2.55

Table 2 – Loss limit calculation for a 300 m MM link segment with 850 nm light source

Wavelength and directional requirements

(1) Horizontal cabling or Cabling Subsystem 1 link segments (TIA-568-C.0) need to be tested in one direction at one wavelength, either 850 nm or 1300 nm for multimode, and either 1310 nm or 1550 nm for single-mode.

(2) Backbone/riser cabling (Cabling Subsystem 2 and Cabling Subsystem 3 link segments) shall be tested in at least one direction at both operating wavelengths to account for attenuation differences associated with wavelength. Multimode link segments shall be tested at 850 nm and 1300 nm; singlemode link segments shall be tested at 1310 nm and 1550 nm. Links that use keyed connectors to implement the fiber polarity can only be tested in the direction prescribed by the keying of the connectors.

Network application standard

For certification, the network application standards such as the IEEE standard 802.3 for Ethernet or the ANSI standard for FibreChannel (FC) must also be considered. High throughput applications (Gbps range and above) require more stringent limits on channel length and channel loss that is depending on the type and bandwidth rating of the optical fiber and the light sources used in the network devices. **Table 3** shows the maximum supported distance and the maximum allowable channel loss for a number of common network applications and for the different fiber types we described earlier in **Table 1**. The maximum channel length (maximum distance supported) is a proxy specification for dispersion. As long as the channel length does not exceed the maximum stated in the standard, dispersion will not cause a communication breakdown.

Field certification shall verify that fiber optic channel length does not exceed the maximum supported distance (the length limit). The installation standards discussed above require the measurement of cable length in order to calculate the 'maximum link attenuation allowance' but the installation standards impose a generic maximum length, which may far exceed the length specified for the application. **Table 3** documents that the length is limited and that it decreases for higher data rate applications depending on the bandwidth rating of each fiber type (a function of the modal dispersion characteristics of the fiber). The maximum channel loss limits decrease (becomes more stringent) with the higher throughput systems.

Application	Wavelength	OM1		OM2		OM3	
		Dist. (m)	Loss (dB)	Dist. (m)	Loss (dB)	Dist. (m)	Loss (dB)
10/100BASE-SX	850	300	4.0	300	4.0	300	4.0
100BASE-FX	1300	2000	11.0	2000	6.0	2000	6.0
1000BASE-SX	850	275	2.6	550	3.6	800	4.5
1000BASE-LX	1300	550	2.3	550	2.3	550	2.3
10GBASE-S	850	33	2.4	82	2.3	300	2.6
FC 100-MX-SN-I (1062 Mbaud)	850	300	3.0	500	3.9	860	4.6
FC 200-MX-SN-I (2125 Mbaud)	850	150	2.1	300	2.6	500	3.3
FC 400-MX-SN-I (4250 Mbaud)	850	70	1.8	150	2.1	270	2.5
FC 1200-MX-SN-I (10,512 Mbaud)	850	33	2.4	82	2.2	300	2.6
FDDI PMD (ANSI X3.166)	1300	2000	11.0	2000	6.0	2000	6.0

Table 3 – Maximum Channel Distance and Loss for multimode optical fiber application by fiber type.

The channel is the total cabling link including all patch cords or equipment cords that link the active devices. **Figure 11** depicts the difference between channel and permanent link. The permanent link describes the link that is considered a permanent part of the building

or datacenter infrastructure. The network equipment is connected to the permanent link using patch cords or equipment cords. Care should be taken to select cords made of the same fiber type as the permanent link optical fiber cabling.

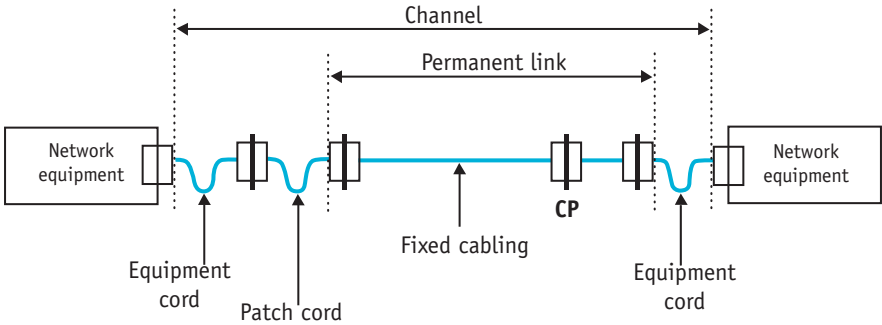


Figure 11 – The channel represents the end-to-end link connecting transmitter and receiver. The fixed cabling – a subsegment of the channel – is called the permanent link. The figure shows a generic horizontal link model that contains optional connections such as the CP (Consolidation Point).

Often an optical fiber link is constructed with several segments or sections and the network equipment is often not installed yet when the cabling installation is certified. It is not sufficient to test each segment against the installation standards. Ensuring that the installed cabling system will support the intended network application requires that the installed channels (end-to-end fiber links) meet the length and loss requirements defined in the application specification as shown in **Table 3**.

You may select one of two methods to assure that the installed channel meets the application requirements before you turn up the network service.

- (1) Calculate the channel loss by adding the data for each link segment in the channel and adding the expected loss contribution of the interconnecting patch cords. IEC standard 14763-3 makes explicit assumptions about the loss of a TRC connection with a link (0.3 dB; see Table A3-1) versus the maximum loss of connections made with commercial patch cords (0.75 dB).
- (2) Measure the channel loss as demonstrated in Figure 12. The end-connections of the channel – connections made with the network equipment – are not included in the channel loss limit. By replacing the equipment cords with TRCs, the loss in the end connections is not part of the test result. The difference in length between the TRCs and the combined length of the equipment cords represents a very small error in loss of 0.0035 dB per meter. If we believe that the mated loss between the link-under-test and the TRCs is lower than the loss with patch cords, the test in **Figure 12** understates the channel loss somewhat. Fluke Networks expects this difference to be much less than the assumptions made in IEC 14763-3.

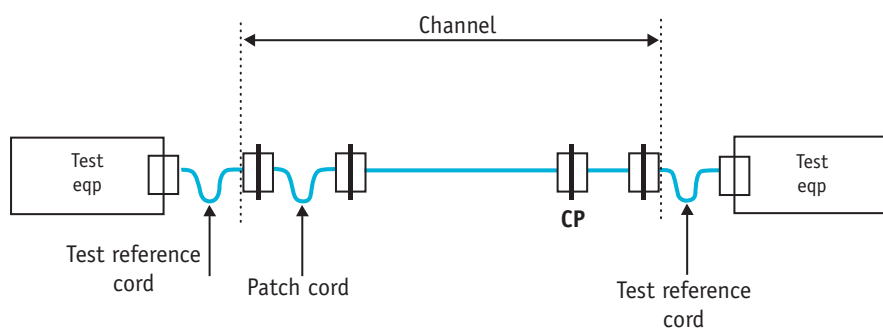


Figure 12 – The end connections in Fig 12 are not part of the channel specification. By replacing the equipment cords with the Test Reference Cords (TRCs) for the channel loss and length measurement, the “error” in the loss measurement is represented by the difference in length between one TRC and the sum of the two equipment cords used to complete the channel. 1 m of cord represents 0.0035 dB.

Optical fiber link polarity

Local area network installations support bi-directional communication by using separate optical fibers in each direction. The cabling system shall provide means to maintain correct signal polarity so that the transmitter on one end of the channel will connect to the receiver on the other end of the channel. Several methods are used to maintain polarity for optical fiber cabling systems. Guidelines are described and illustrated in Annex B of TIA-568-C.0. Duplex connector types and array connector systems that allow the fiber ordering arrangement to be maintained relative to the plug’s keying features should be selected.

Cabling Certification

Select the performance standard

The standards define a minimum test procedure consisting of:

1. Measurement and evaluation of the link loss using an ‘optical loss test set’ (OLTS) – some standards refer to this test tool as a ‘light source and power meter’ (LSPM). OLTS and LSPM tend to be used interchangeably. In this document we will choose the terminology OLTS for certification test tools that automatically measure the length of the link-under-test whereas we will use the term LSPM to designate test sets that do not measure the link length – and therefore may require some manual calculations to interpret the measured values. The light source is connected to one end of the fiber-under-test while the power meter is connected at the other end.
2. Measurement and evaluation of the link length. The length must be known to calculate the loss test limit for many installation standards – the maximum loss to be contributed by the optical fiber in the link loss limit value.

The length also plays an important role to certify the link for a specific network application. As shown in **Table 3**, the maximum length of a fiber channel for a given network application depends on the fiber type and bandwidth rating of the fiber.

3. Verification of link polarity

Steps 1 through 3 constitute the minimum certification testing requirement, also referred to as 'Basic Certification' or 'Tier 1' testing. 'Tier 2' testing also known as 'Extended Certification' test is optional and includes the Tier 1 tests plus the addition of an OTDR link analysis (with trace and/or event table). The OTDR analysis can be used to characterize the components within the installed fiber link resulting in an indication of the uniformity of cable attenuation and individual connector insertion loss, individual splice insertion loss and other "events" that may be detected. An OTDR analysis provides an overall loss measurement for the link. The standards define that the basic certification (Tier 1) loss measurement must be executed using OLTS or LSPM equipment which when properly used provides a higher accuracy loss analysis.

The end-user should specify the test standard to be chosen for the optical fiber certification test procedure. A test standard defines the tests to be executed and the limits or maximum allowable values for the tests. As we have discussed, when testing or certifying links that must support high-throughput applications (data rates in the Gbps range), the application standards impose exacting limits for channel length and channel loss. When you need to certify the cabling to support such applications it is important that (a) you select the corresponding application standard in the OLTS setup and (b) certify the channel configuration.

Certification – Process and equipment requirements

Table 3 illustrates that the channel loss limits for high-throughput network applications are relatively small. In order to make the Pass/Fail decisions with confidence, the test procedure must be executed with precision and with accurate OLTS or LSPM equipment. When the loss limit value is 2.6 dB (10GBASE-S), a measurement error of even 0.25 dB constitutes an error approaching 10% of the limit value. This section will review the procedural steps and equipment requirements to achieve accurate and repeatable measurements. Two issues have proven to make a critical contribution to the topic of measurement accuracy:

- (1) The reference for the loss measurement
- (2) The launch condition of the light source into the link-under-test

Measurement units

The dB or decibel expresses a ratio of power levels using a logarithmic function. If we represent the input power into a black box as P_{in} and the output power as P_{out} , we calculate the amplification or attenuation of the signal processed through the black box in dB using the following function:

$$10 \times \log_{10}(P_{out} / P_{in})$$

Note that when P_{out} , is greater than P_{in} , the black box has amplified the signal and the mathematical formula above yields a positive number. If on the other hand P_{out} is lower than the P_{in} , the signal has been attenuated and the formula produces a negative number. Since the latter is always the case when we measure passive cabling and since the standards use the name “Loss”, the negative sign is omitted in reporting the cabling loss in dB.

An absolute power level is typically expressed in watt (and its multiples like megawatt in the electrical power generation world or fractions of a watt like milliwatt or even microwatt in electronics). In the communication field, an absolute power level P is often expressed as a ratio to one milliwatt (mW) using the decibel. We apply the formula stated above but replace the reference (input power level) with the absolute power level of 1 mW.

$$1 \text{ dBm} = 10 \times \log_{10}(P/\text{mW})$$

The ‘m’ in the symbol dBm indicates a power level referenced to one milliwatt.

Note: the dB scale is not a linear scale as the numbers in the table below demonstrate

dB loss	Power output as a % of the power input	% of power lost	Ratio P_{out}/P_{in}
1	79%	21%	
2	63%	37%	
3	50%	50%	1/2
5	32%	68%	
6	25%	75%	1/4
7	20%	80%	1/5
10	10%	90%	1/10
15	3.2%	96.8 %	~1/30
20	1%	99%	1/100
30	0.1 %	99.9%	1/1000

Table 4 – Decibel expresses a ratio between two power levels. The logarithm of the ratio turns this unit non-linear.

Set the reference – principle

The principle of the loss measurement is based on the difference of two power measurements. **Figures 13 and 14** show the principle of the fiber loss measurement of a link. In **Figure 13** the light source is connected to the power meter with one 'test reference cord' (TRC). A TRC is a high-quality fiber cord between 1 to 3 m with high performance connectors at either end. The end-faces of the connectors should be treated by the manufacturer to provide scratch resistant hardened surfaces that support a multitude of insertions without degradation in performance. It is critically important that the end-faces of TRCs are kept very clean and are inspected regularly – and cleaned if necessary – throughout the day when certifying optical fiber links.

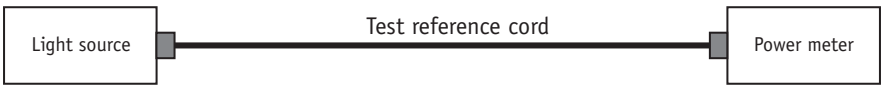


Figure 13 – Principle for connections to set the reference for an optical loss measurement

The light source in **Figure 13** launches the light into the TRC which directs the light into the power meter. The power meter measures the light energy level and typically expresses it in dBm (Refer to sidebar). The reference power reading with LED light sources falls in the range of -18 dBm to -20 dBm. The -20 dBm level corresponds to 0.01 mW. When testing a singlemode fiber link with a laser light source, the reference power measurement may yield -7 dBm, which corresponds to approximately 0.2 mW, a power level that is about 20 times stronger than the LED light output. Therefore, always use caution that you do not look into an active fiber link – light used for data communication falls outside the visible spectrum but can cause permanent harm to your eye!

The reference power measurement compensates for uncertainties that could translate into measurement errors (inaccuracies). The exact power output level of the light source is unknown and the amount of light coupled into the TRC varies every time we make a connection. We must accept that there is some loss in the connection between the light source and the TRC. Because of the reference measurement, we do not need to know exactly how much this coupling loss is as long as it remains unchanged throughout the testing job. Therefore, the TRC shall not be removed from the light source until we quit or set a new reference.

The coupling of light from the TRC into the power meter is less variable since the power meter should be equipped with a wide angle input to capture all of the light from the TRC. This coupling must be clean and the connectors must be properly seated to ensure that the reference measurement truly establishes “the reference”. Many testers like the fiber loss/length modules with the DTX Series CableAnalyzer™ automatically verify that the measured reference power level is within the acceptable range for the light source. This provides some level of assurance that the reference is valid but it does not alleviate the need to

make sure you use high-quality TRCs that have been inspected to be clean.

After we have established this reference power level, we move to the measurement connections as shown in **Figure 14** with the following actions:

- (1) First, do NOT tamper with the connection between the light source and the TRC in any way.
- (2) Connect the light source and TRC at one end of the link-under-test (connector C1).
- (3) Connect a second TRC ("Added TRC") between the other end of the link-under-test (C2) and the power meter. This second TRC should exhibit the same quality as the first one (used to set the reference). It too must be inspected to ensure that both end connections are clean.
- (4) Make a power measurement while the light source transmits the light through the link-under-test to the power meter.
- (5) The power meter measures the light energy through the link-under-test and produces a result in dBm.

Assume that the power measurement through the link under test is -23.4 dBm and the reference power level is -20 dBm. By subtracting these two measurement readings, we find the loss caused in the link-under-test. In this example, the loss is $-20 - (-23.4)$ or 3.4 dB. Note that a loss is expressed in dB (in contrast with absolute power measurements expressed in dBm). An OLTS automatically calculates the difference in power levels (the loss of the link-under-test) in dB and compares the result to the limit for the link-under-test. If the measured loss is less than or equal to the limit, the test passes.

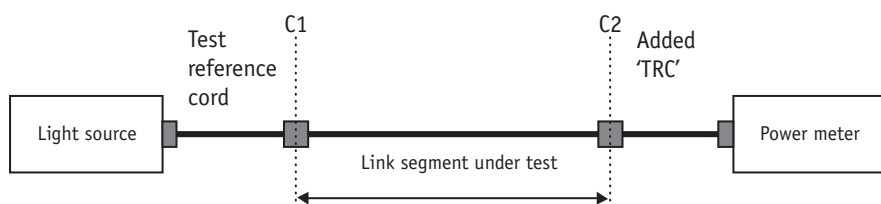


Figure 14 – Connection of 'Light Source' and 'Power Meter' for an optical loss measurement

Different methods to set the reference

The implementation of the loss measurement principle shown in **Figures 13 and 14** is the 'one-jumper' method. One jumper or one TRC is used to set the reference. This method is preferred for the loss test of all premises wiring cabling. These cabling systems are characterized by relatively short fiber lengths but may contain several connections. As the example loss calculation in **Table 2** demonstrates, the maximum loss allowed in a short 300 m link by the two connectors is 1.5 dB out of the total budget of 2.55 dB; the connecting hardware loss constitutes 59%. This underscores the need to make sure that all connection losses must be properly included in the loss measurement.

When we analyze the reference method shown in **Figure 13**, the TRC does not introduce a connection between the light source and power meter. The TRC connects to each device but does not add any connections. Follow the light path between light source and power meter in **Figure 14** to realize that the loss in connection C1, the loss in the link-under-test and the loss in connection C2 are fully accounted for in the measurement. The loss measurement also includes the loss of the “Added TRC.” The maximum loss represented in a 2 m TRC is 0.007 dB (**Table 1** shows that the maximum loss for the fiber types used in premises wiring is 3.5 dB/km or 0.0035 dB/m). Another difference between the reference measurement and the link loss measurement is a new connection between the ‘Added TRC’ and the power meter. This difference is also very small (assuming the end-faces of the ‘Added TRC’ are indeed clean) since the meter is equipped with a wide-angle lens to capture all the light transmitted by the link-under-test. We judge the measurement error due to the ‘Added TRC’ to be less than 0.01 dB which also happens to be the resolution of a power meter.

The one-jumper method can only be applied if the connector in the power meter and the end-connectors of the link-under-test are the same type (for example, SC connectors). After setting the reference, we disconnect the TRC from the power meter and are only able to connect this TRC to the link-under-test if the end-connector of the link (C1 in **Figure 14**) properly mates with this TRC.

To be able to use the preferred one-jumper method with different connector types, many of Fluke Networks’ power meters, to include the SimpliFiber Pro, are equipped with a removable adapter. A set of hybrid TRCs assures proper measurement connections while taking full advantage of the accuracy of the one-jumper method.

The applicable standards listed in **Table 5** make provisions for three different methods to set the reference for an optical fiber loss test. The names of these methods in the different standards documents can be confusing. We will use the following names in this document: one-jumper method, the two-jumper method and the three-jumper method. The two-jumper method and the three-jumper method are discussed in Appendix 3.

Name in this document	IEC 14763-3	IEC 61280-4-1 (multimode)	IEC 61280-4-2 (singlemode)	TIA-526-14A (multimode)	TIA-526-7 (singlemode)
One-jumper	One-jumper	Method 2	Method A1	Method B	Method A.1
Two-jumper	–	Method 1	Method A2	Method A	Method A.2
Three-jumper	Three-jumper	Method 3	Method A3	Method C	Method A.3

Table 5 – Reference to test method names in the installation standards

Launch conditions

The goal of any certification measurement is to provide Pass/Fail indications the end-user and the installation contractor can rely on. The ‘launch conditions’ have proven to have a major influence on the accuracy, consistency of optical fiber loss measurements.

We reviewed that the light in graded-index multimode fiber propagates in many modes. The number of modes that are excited by the launch and the energy level in each mode affects the power measurements. If the *launch conditions* are not controlled from test tool to test tool, each tool may provide a different measurement and test results; this is a certain indication that none of them are correct or trustworthy.

The goal is to control the launch conditions such that compliant test tools produce results that fall within a narrow range around the true loss value.

Factors that influence the launch conditions. LEDs are the preferred light sources to test the link loss for multimode fiber links. We discussed how VCSELs have become the light source of choice for all higher-throughput network applications using multimode fiber because VCSELs meet the modulation capability to provide short pulses in rapid succession to support the data rate for the 1 and 10 Gbps applications. But VCSELs are not well suited for loss testing because each VCSEL may excite a different set of modes with varying energy levels in these modes. Furthermore, loss testing is performed with a constant light wave rather than a modulated signal.

LEDs produce a cone of light that is evenly spread over the end-face of the fiber, even beyond the core. LEDs create an “overfilled launch” condition. The degree of overfill, however, produces significant variations in the loss measurement. A laser light source including a VCSEL creates an “underfilled launch” condition. These sources shine a narrow cone of light in the center of the core. An underfilled launch condition may not properly detect problems in the fiber link and may consequently provide a more optimistic test result.

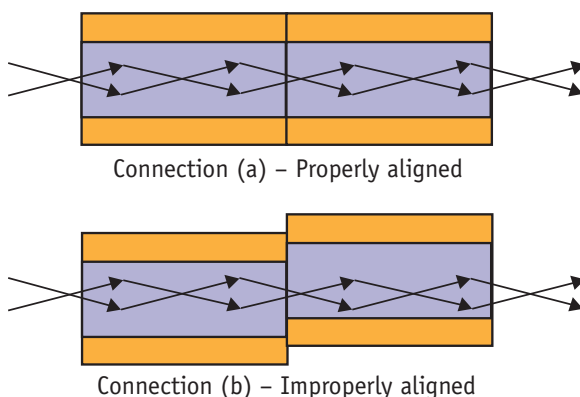


Figure 15 – Testing the two connections shown with underfilled launch conditions may not detect the misalignment problem in the optical cable

The misaligned connection in **Figure 15 (b)** provides an example in which the loss measurement with an underfilled launch cannot detect the full impact of the misalignment. It reports a lower loss value (optimistic loss value) than a test executed with an overfilled light source.

Controlling launch conditions. Over the years, better methods have been devised to control these overfilled launch condition into a narrow range with the goal to produce repeatable and accurate loss test results. The standards established two independent metrics to characterize and control the launch conditions. They are the Modal Power Distribution and the Coupled Power Ratio.

The Modal Power Distribution measures the relative power level in the different modes transferred between the light source and the TRC. This metric must be satisfied by the design of the equipment such as the selection of the LED diode and the coupling inside the light source instrument between the LED and the internal fiber connection. (All fiber optic test modules designed and manufactured by Fluke Networks after 2002 satisfy the MPD requirements.)

Coupled Power Ratio (CPR) is a measure of the amount of modal filling in a multimode fiber (test reference cord). It became popular because it could be measured in the field. Both the light source and the TRC can be rated with a CPR index. A CPR value is measured as the loss between a multimode TRC coupled into a singlemode TRC. When the light in the multimode fiber contains significant energy in the high order modes, the loss in this coupling will be greater than when the multimode fiber carries less energy in the higher order modes. The value of this loss measurement defines the desired overfilled condition when an MPD compliant light source is used. The standards specify CPR loss values; a CPR index of 1 is the desired and recommended rating for the certification measurements of multimode optical fiber links.

Mandrel. Since test equipment with an MPD compliant light source in combination with TRCs with CPR rating 1 may deliver varying loss test results, further steps have been designed to limit this variability in results. The use of a mandrel for testing multimode optical fiber links is required in order to obtain more accurate loss measurements. The proper mandrel limits measurement uncertainties and enhances the accuracy of the loss measurement.

A mandrel is a small cylinder with a specified diameter that depends on the core size and the construction of the TRC fiber. **Table 4** shows the mandrel sizes defined in the ANSI/TIA-568-C.0 document for several fiber constructions.

Fiber core/clad- ding size (μm)	900 um buff- ered fiber (mm)	2.0 mm jacketed TRC (mm)	2.4 mm jacketed TRC (mm)	3.0 mm jacketed TRC (mm)
50/125	25	23	23	22
62.5/125	20	18	18	17

Table 6 – Acceptable mandrel diameters for multimode cable types (five wraps)

The multimode TRC is to be wrapped five times around this cylinder to achieve the desired effect of filtering or stripping the higher undesirable modes from the launch condition. Recall that the higher order modes – modes traveling through the outer range of the core – refract out of the core when the fiber is bent.

The five well-defined wraps control the modes that will enter the link-under-test to measure the loss. The TRC connected to the light source must be attached to the mandrel as shown in **Figure 16** and remain attached for all testing.

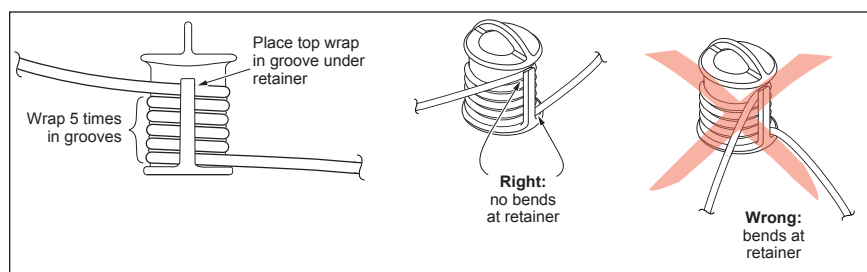


Figure 16 – How to wrap the optical fiber test reference cord correctly around a mandrel

The mandrel also improves the accuracy of the measurements by establishing a realistic test reference value. When we examine the setup in **Figure 13**, the overfilled launch condition excites the highest order modes in the TRC and may also launch some light into the cladding of the TRC. The higher order modes in the core and the light in the cladding will not travel very far but may travel the short distance of the TRC if the TRC is not subjected to any bends. The wide-angle input to the power meter captures the light energy in the cladding. This light will however not “survive” in the link-under-test (unless it would be a very short and straight fiber run). Without a mandrel, the power meter measures light energy during the reference setting that will not travel through the link-under-test. The power level established during the reference test is higher than it should be which will overstate the loss. In the example discussed above, we assumed that the power meter measured -20 dBm for the reference setting. When we do not use a mandrel wrap, the power level may actually be as high as -18 dBm with the same power source. The loss calculation now yields $[-18 - (-23.4)]$ dB or 5.4 dB rather than 3.4 dB. In essence, we overstated the loss by 2 dB. This is a huge error since the highest order modes and the light entering the cladding cannot travel very far in the link-under-test.

Future launch condition control method

At the time of this writing, standards committees are defining a method that improves on the launch conditions today controlled by MPD, CPR and mandrel wraps. The proposed method is based on the concept of ‘Encircled Flux’ (EF), which fine tunes and controls the modes launched in the link-under-test. This method is currently still under study with the ultimate goal to further improve the accuracy and consistency of power measurements and loss tests in multimode links.

4. Fiber Verification Testing

Fiber verification testing (including end-face inspection and cleaning) should be practiced continually as standard operating procedure. Throughout the cable installation process and prior to certification, loss of cabling segments should be measured to ensure the quality of the installation workmanship. This type of a test is normally accomplished with an LSPM test set. Fiber verification test tools are typically less expensive tools; they can also effectively be used to troubleshoot troublesome links. A quick inspection of the end-to-end link loss may provide the indication whether or not the optical fiber cable is suspect or whether other network functions are the cause of the detected malfunction.

An LSPM determines the total light loss along a fiber link by using a known light source at one end of the fiber and a power meter at the other. But before the test can be done, as described earlier, a reference power level from the source is measured and recorded to set a baseline for the power loss calculation. After this reference is established, the meter and source are plugged into the opposite sides of the fiber link to be tested. The source emits a continuous wave at the selected wavelength. On the distant end, the power meter measures the level of optical power it is receiving and compares it to the reference power level to calculate the total amount of light loss (**Figure 17**). If this total loss is within the specified parameters for the link-under-test, the test passes.

A loss budget should be well established and used as a benchmark during cabling installation. If this type of verification testing is performed during installation, it can be expected that yield will increase and certification testing will go smoother.

LSPM test sets have historically been more difficult to use, requiring manual calculations and subjective interpretation by an experienced technician. However, newer instruments have eliminated time-consuming loss calculations by automating the process of comparing power measurements versus set references.

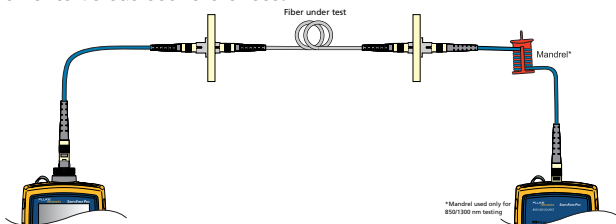


Figure 17 – Conducting an LSPM test

While convenient, basic verification of end-to-end loss using an LSPM set does not specify where the trouble areas are, making failures difficult to locate. Even in instances where the loss is within a specified threshold, the LSPM set does not provide any warning or indication of where a defect or problem may be located. In other words, although an entire link may pass, it is possible that individual splices or connections within it may fail industry specifications, creating a potential problem in the future during adds, moves, or changes where multiple dirty connectors can potentially be grouped together to result in a failure. An OTDR is the proper test tool to pinpoint locations (connections) displaying a high loss or reflectance.

5. How to Certify Fiber Optic Cabling with OLTS and LSPM

Industry standards require testing with an LSPM or OLTS to certify that the loss of each link meets performance standards. As mentioned previously, this is referred to as 'basic' or Tier 1 Certification.

It is a double-ended test which produces an absolute loss measurement which is then compared with installation cabling standards and/or channel application standards. Fluke Networks' DTX CableAnalyzer and OptiFiber OTDR can be equipped with optional multimode or singlemode fiber test modules that automate most of the test and make 'basic' or Tier 1 certification very easy.

Note that an OTDR also provides a loss results for the total link but this measurement is based on the reflected light energy. The standards demand that the basic certification be executed with an OLTS or LSPM. These link loss results provided by using a light source on one end and a light meter at the opposite end are more accurate if properly executed.

The following steps should be followed to perform a basic loss length certification test.

- Establish Pass/Fail test limits
- Choose a test method and set a reference
- Run the test and save results
- Export to LinkWare to manage and archive the test results; LinkWare is Fluke Networks' popular and widely-used free data management software that lets you create printed or electronics reports.

1. Establish Pass/Fail limits in accordance to what your certification goals are. In this example, we will establish limits for the total allowable loss based on an application standard using the Fluke Networks DTX Series tester equipped with the DTX-MFM2 fiber loss test modules (for multimode). If you need to certify singlemode fiber use the DTX-SFM2 modules.

- a. Once the tester is turned on, turn the rotary switch to 'Setup' and select 'Instrument Settings' to input the operator name, job name etc.

- b. Select 'Fiber Loss' from the Setup screen as shown in **Figure 18a**. Under this setup screen, you will choose from a menu of standards to select the correct limits. Select the 'Test limit' option as shown in **Fig 18b**. Note that the selected fiber type limits the test limit choices. Popular fiber types are also included in the instrument menu.

As **Figure 18b** shows, the same setup screen allows you to select the 'Remote End Setup'. When using the DTX Smart Remote equipped with the fiber test module, select 'Smart Remote' as we have done in this example. In this mode, the tester automatically measures the length of the link-under-test.

Lastly, this screen provides the option to tell the tester whether you need to test the link-under-test in both directions. If this is the case, remember never to disconnect the TRC from the test modules; always swap the TRC at the connection with the link-under-test.

- 2. Choose a reference method and set a reference.** As described earlier, setting a reference is a critical aspect of a loss test to obtain accurate test results. The power meter and light source are connected together and the power level is measured by the light meter to establish the 'reference' for loss calculations. The steps for setting a reference are as follows:

- Step A. Turn the rotary switch to 'Special Functions' and choose 'Set Reference'
- Step B. Now press 'Enter' and connect the TRCs between main and remote as shown on the screen and press test to make the reference measurement.

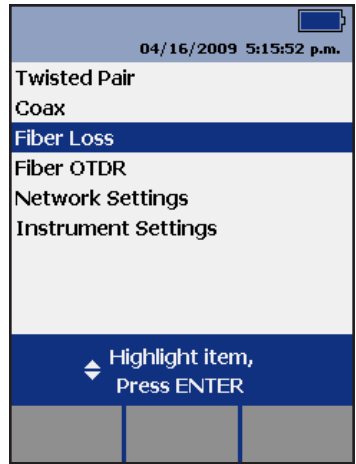


Figure 18a

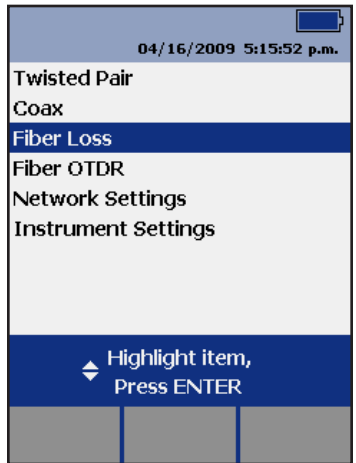


Figure 18b

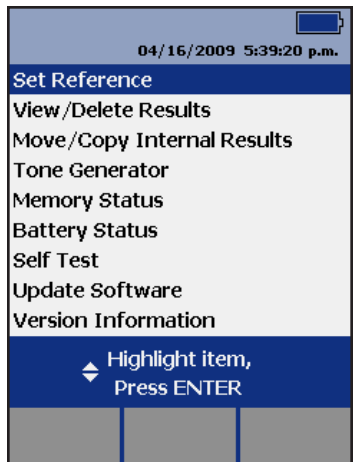


Figure 18c

The earlier discussion on setting the reference showed the preferred one-jumper method **Figure 13** and **Figure 14** which is called ‘Method B’ in the test instrument. Note that with the DTX Series in Smart Remote setup, we are going to test the two fibers that make up the transmission link in one test. Each fiber test module is equipped with a light source and light meter. In the setup, we will use two duplex TRCs. One fiber will connect the Output (light source) at the main unit to the Input (light meter) at the remote unit. The second connects the Output at the remote unit to the input at the main unit. The

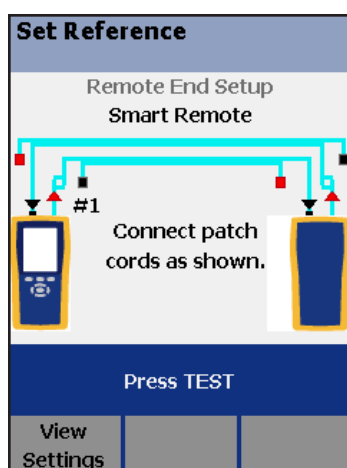


Figure 18d

Special Note: The DTX TRCs use the following convention in order to quickly make connections and verify the polarity of the link-under-test: The light enters the cord at the red boot; the light leaves the TRC at the black boot. So, one end of a TRC has a red boot and at the other end of that same cord is a black boot. The light travels from red to black. The DTX screen display shows the boot color (**Figure 18d**).

Figure 18e shows a schematic representation of this reference setup. This figure uses a different color for the two duplex cords. These colors do not relate to the real cords but were chosen to add clarity to the figure. The yellow cord connects the Output (light source) of the main unit’s fiber module to the Input (light meter) of the remote unit. One of the yellow cords is not connected in the reference setting. One of the darker colored cords makes the connection in the opposite direction. **Figure 18e** also shows the location of the mandrel near the end with the red boot that is to be connected to the light source. The duplex cords have one longer leg with the red boot. After this leg has been wrapped around the mandrel, the lengths of both cords in the duplex arrangement are equal.

The DTX fiber modules’ Output ports are always SC connectors. The removable adapters for the Input ports are chosen to match the end connectors of the link-under-test. The example in **Figure 18e** depicts the example in which the link-under-test is equipped with LC connectors.

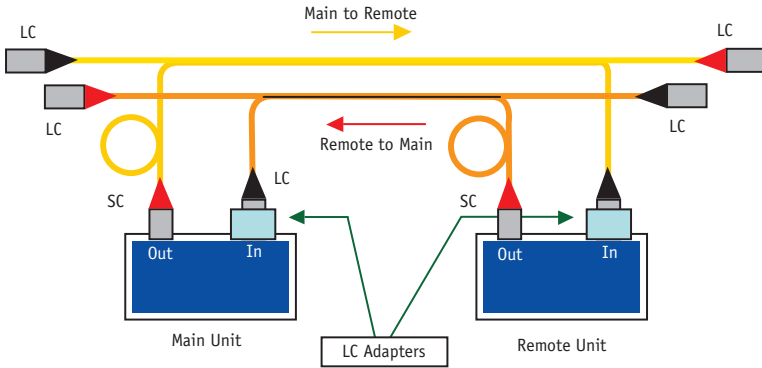


Figure 18e – Schematic representation of setting the reference with duplex TRCs for a link-under-test ending with LC connectors. The ring near the red boot indicates the location of the mandrel (for multimode fiber).

Step C. After the tester measures the reference power level, it displays these values as shown in **Figure 18f**. If your reference values are acceptable, press the F2 soft-key to store these values and to proceed with link certification.

- i. Acceptable reference with DTX-MFM or DTX-MFM2
 1. -20dBm nominal level with LED 62.5 μ m
 2. -22 dBm nominal level with LED 50 μ m
- ii. Acceptable reference with DTX-GFM, DTX-SFM, DTX-GFM2 or DTX-SFM2
 1. -7dBm nominal level with VCSEL or laser

View Reference	
Remote End Setup: Smart Remote	
850 nm	1300 nm
Input (dBm)-19.16	-19.51
Output (dBm)-18.54	-18.92
Test Method: Method B	
Reference set:	
05/08/2009	4:48:03 p.m.
OK	

Figure 18f

Step D. Now disconnect your TRCs **at the Input ports only** and create the connection that is shown on the screen (**Figure 18g**). Disconnect the black boots from the input ports and connect the unused ends with the black boots in the duplex cord set to the adapter on the input port of the unit to which the duplex mate has been connected. Now you have separated the main and remote units so that you can connect a unit at each end of the optical fiber link to be tested.

View Connections	
Remote End Setup Smart Remote	
#1	#2
Patch Lengths	OK

Figure 18g

If you need to test a link for which Fluke Networks does not or cannot offer adapters such as MT-RJ connectors, consult **Appendix 3** to review alternate methods the set the reference.

Guidelines for setting a reference

- Use high-quality TRCs
- Clean TRC ends before you set the reference
- Let the tester warm up to a steady-state internal temperature (about 10 min. with ambient temp and storage temp difference of <20°F)
- Use preferred one-jumper reference method
- Plug the SC adapter with red boot plugs into the transmitter (OUT connection)
- Do not unplug red boot (on source) after setting the reference
- After the reference is set do NOT disconnect TRC from light source
- For a multimode optical link, use the proper mandrel
- Reference must be re-set after each time the units are powered down
- Ensure to maintain precise launch conditions of the reference

3. Run an autotest

Select “Autotest”. The test standard you selected for an Autotest determines the test parameters to be measured and the Pass/Fail criteria for each test

Polarity. When you run a successful Autotest using the DTX Fiber Modules, you will be able to ensure polarity.

- Connect the black boot of the TRC to the fiber in the link-under-test that is transmitting the light and needs to connect at this end of the link to the transmitter of the network device. (Light leaves the TRC at the black boot; the red boot end of that cord is connected to the Output on the tester)
- Connect the red boot of the TRC to the fiber in the link-under-test that is receiving the light from the other end of the link.
- When the connections to the link-under-test are established, the instrument will chirp a “happy tone” to let you know whether polarity has been established.

Length. The tester measures the length as well as the link loss. When you select an application standard during the setup, it includes the maximum length for the application depending on the bandwidth rating of fiber used in the link-under-test. **Table 3** provides an overview of this dependency.

Make sure that you are using the appropriate fiber test adapter with a connector that matches the fiber patch cord or the patch panel.

Connect TRCs to the link or channel to be tested: repeat the process explained in **Figure 18g**.

Bidirectional testing. If you want to test each fiber in both directions, do not forget to select that option in the setup screen (see **Figure 18b**). When the tester prompts you to make the connection to test in the second direction, remember to switch the TRC at the link end. DO NOT remove the TRCs from the tester connections.

Test Results. Be sure to save results before moving onto the next fiber or testing in the other direction. **Figure 19** shows the detailed measurements of a fiber; note that each fiber is tested at both of the wavelengths demanded by the installation standard.

Applications standards, on the other hand, only specify performance for the wavelength of the applications. For example, the 10GBASE-S standard specifies the link requirements at 850 nm. The name “input” fiber or “output” fiber in the test result screen of the tester refers to the port in the main unit to which the fiber is connected. The result shown in **Figure 19** pertains to the fiber that is connected to the input port at the main tester unit. The screen title “Loss (R ->M)” which means Loss from the Remote unit to the Main unit also indicates the fiber for which the result is displayed.

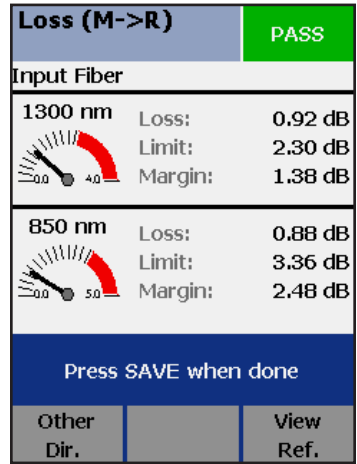


Figure 19 – Loss test results for the fiber connected to the input port on the main tester unit. The result includes the loss for both multimode wavelengths (installation test standard)

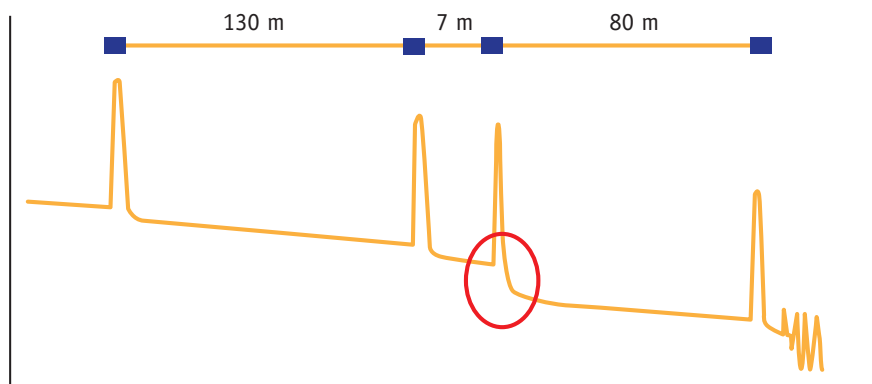
Once you have tested all the links and saved each record, results can be downloaded to a PC and managed with LinkWare Results Management software. LinkWare allows you to manage and inspect any stored test result on your PC screen. You can also print a Summary Test Report for the job as well as a professional report for each link tested. LinkWare lets you create or emailed reports in PDF form.

6. How to Certify Optical Fiber Cabling with an OTDR

TIA TSB 140 & ISO 14763-3 recommend OTDR testing as a complementary test to ensure that the quality of fiber installations meet component specifications. The standards do not designate Pass/Fail limits for this test. It is recommended that generic cabling requirements for components and design criteria for the specific job be considered. An OTDR can be used bi-directionally as a single ended tester for or with a receive fiber for certification testing.

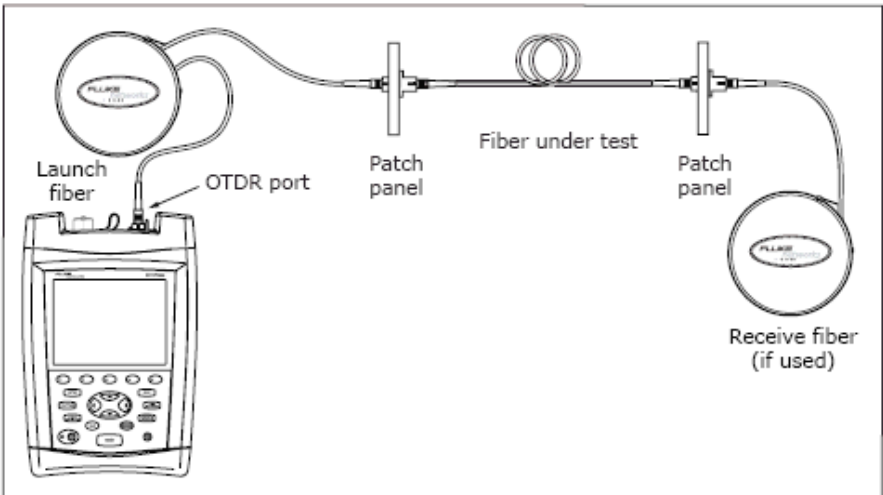
What you need to know about OTDRs. OTDRs were once laboratory equipment that were difficult to operate and impractical for field use. They were big, heavy and complicated for inexperienced technicians to set up for a test and operate accurately. Once a test was performed, it was difficult to understand test results. This led to a stigma of fear and confusion. However, many new OTDRs today many new OTDRs are small, light, and easy to use. An ordinary technician can now perform troubleshooting like an expert – but a basic understanding of how an OTDR works is still helpful.

- **Basic operation.** An OTDR infers loss, reflectance, and location of events. It sends pulses of light into a fiber and uses a sensitive photo detector to see the reflections and plot them graphically over time. In order to accurately test, the optical characteristics of the fiber must be determined and set prior to running the test.
- **OTDR trace.** The OTDR plots the reflectance and loss over time in a graphical “trace” of the fiber. Experienced technicians can “read a trace” and explain it. For example, on the below trace, an experienced eye can spot that one side of a cross connect is exhibiting excessive loss.



Sample OTDR trace with high loss connector at 137m

- **Event analysis software.** The latest OTDRs run sophisticated software that automate trace analysis and enable automatic test set up parameters. Fluke Networks' OTDRs can automatically choose setup parameters, not only telling you where events (instances of reflectance and loss) are on the trace, but also telling you what the events are while qualifying each of them.
- **Dead zone.** This is the shortest fiber length an OTDR can detect. It can also be described as the distance after a reflective event after which another reflection can be detected. All OTDRs have dead zones and should be used with an appropriate launch fiber so that you can measure the first connection on the link.
- **Dynamic range.** Determines the length of fiber that can be tested. The higher the dynamic range, the longer the fiber-under-test can be. There is a drawback, however, as the dynamic range increases, the wider the OTDR pulse becomes – and as a result, the deadzone increases.
- **Ghosts.** Not as scary as they might seem, ghosting is caused by an echo due to highly reflective events in the link under test. Fluke Networks' OTDRs identify ghosts on the trace and tell you where the source of the ghost is so that you can eliminate it.
- **Gainers.** Another misunderstood phenomenon on an OTDR trace is called a gainer. Simply put, a gainer is an apparent negative loss at an event where there is a change in the optical performance. This is usually due to a mismatch between the index of refraction of two spliced fibers or connection of a 50µm multimode fiber into a 62.5µm fiber. This type of event will often exhibit excessive loss in the other direction.



OTDR Certification Set-up

Setting up for OTDR Certification Testing

Setup: Turn the rotary switch to 'Setup' and choose 'Settings' from menus in five setup screens.

1. First, select which port you want to test from (multimode or singlemode), what test limit you want to use, the fiber type, and desired wavelength.

- It is possible to create multiple sets of OTDR test limits and select one for a particular job. Each OTDR test passes (**Figure 21**) or fails (**Figure 22**) based on a comparison against the selected set of test limits.

2. On the second setup screen, you may then set launch fiber compensation, designate which end you are testing from, and notate what you want to call each end of the fiber.

Using Launch Fiber Compensation LFC

Launch fiber compensation is used to simplify testing and remove the launch and receive fibers' losses and lengths from measurements.

- It shows you where your launch (and/or receive) fiber is on the trace, and eliminates it from the certification test results. If you are a contractor, your customers want to know where an event is in their fiber plant, not where it is on your test setup. When you enable 'LFC', a connector that is 50m from the patch panel will show up at 50m, not 150m on the trace. Just turn the rotary switch to 'Setup', go to the 2nd tab, and enable 'Launch Fiber Compensation'. Then turn it again to 'Special Functions', and choose 'Set Launch Fiber Compensation'. Choose 'Launch' only if you are just using a launch fiber, or 'Other Options' if you are also using a receive fiber.

3. Third, designate the fiber characteristics or allow default to the selected fiber in the first step or choose 'User Defined' and select 'Numerical Aperture' and 'Back-scatter coefficient' for the fiber-under-test.

OTDR Results		PASS
HBL LIMIT Multimode 50 Dual 850/1300 nm End 1: DATA CENTER		
✓ Length	55.5 m	
✓ Overall Loss	0.19 dB	
✓ Largest Event	-0.04 dB	
View Trace	View Events	View Limits

Figure 21 – "Pass" Screen on the DTX Compact OTDR

OTDR Results		FAIL
HL Multimode 50 Dual 850/1300 nm End 1: DATA CENTER		
✓ Length	312.0 m	
✓ Overall Loss	1.98 dB	
✗ Largest Event	0.78 dB	
View Trace	View Events	View Limits

Figure 22 – "Fail" Screen on the DTX Compact OTDR

4. Now choose from a menu to set 'Distance Range', 'Averaging Time'.
5. Finally, choose from the menu to set 'Pulse Widths' and 'Loss Threshold'.

With the DTX Compact OTDR, many settings such as 'Distance Range', 'Averaging Time', 'Pulse Widths', and 'Loss Threshold' can be automatically set. Just turn the rotary switch to 'Autotest', and when you push the test button, the OTDR will choose the most appropriate setting for the fiber that you are testing.

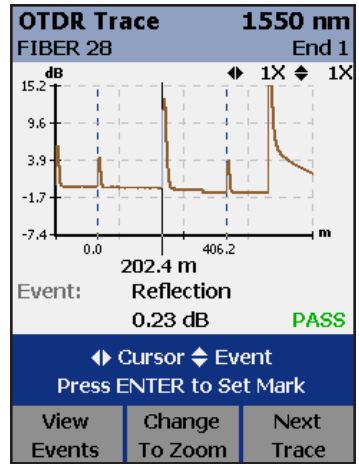


Figure 23 – Trace Screenshot on the DTX Compact OTDR

Running an autotest. Now that you are all set up for testing, turn the dial to 'Autotest', plug in your launch fiber and press 'Test'. If it passes, press 'Save', name the test, and test the next fiber. If you want to see a trace just press the f1 softkey. The event table and limits are also accessible via softkeys on the main screen.

Summary of extended certification

- OTDR traces characterize the individual components of a fiber link: connectors, splices and other loss events. Extended certification compares the data to specifications for these events to determine if they are acceptable
- Critical because it identifies faults that may be invisible to basic certification
- Evidence that every component in a fiber optic cabling system was properly installed

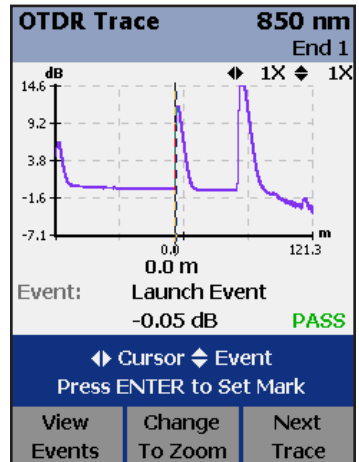


Figure 24 – "Pass" Trace Screenshot on the DTX Compact OTDR

As with the first tier of testing, results can be downloaded to a PC and managed with LinkWare Results Management Software. It is easy to merge OTDR test results with the other records if the same naming sequence is used. The FiberInspector option for OptiFiber also allows end-face images to be merged into the same records to prove cleanliness and combined to generate professional reports that combine all the test data into one document. These can be easily created and printed out or emailed in PDF form.

Cable certification test strategy

There are several possible ways to perform a complete certification test of fiber optic cabling. The standards are clear about defining required and optional tests, test limits and test equipment that may be used. But they do not suggest how the testing should be performed for optimum efficiency in the field. Based on decades of working with contractors, installers, technicians, Fluke Networks has developed proven, best-practice procedures to perform a complete fiber certification in the most efficient way.

- Make sure that design criteria and test limits are established before installation
- Confirm proper fiber strand polarity, end-face conditions, and verify loss with simple verification tools during installation
- Perform extended tests using the tier 2 certification tests (OTDR analysis) as the first certification step. Doing so:
 - Ensures connector performance meets generic cabling standards or system designer's requirements
 - Qualifies workmanship for cabling installation
 - Identifies problems for immediate troubleshooting with OTDR

- Secondly, perform basic tier 1 test for the *channel* against the *application standard*. Certifies channel length and loss and calculates margin based on the standard

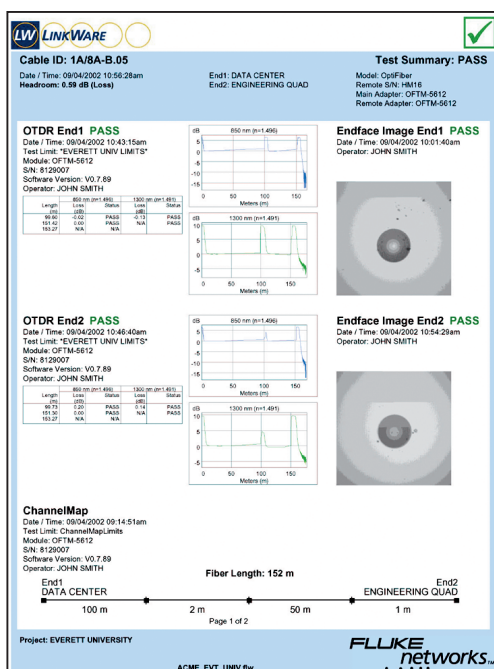


Figure 25 – Sample LinkWare Results Management Software printout

- If bidirectional testing is not required, measure channel loss at the wavelength of the application

7. Common Faults

Insufficient power or signal disturbances resulting from common faults cause failures in optical transmission.

Fiber optic connections involve the transmission of light from one fiber core into another. Fiber cores are smaller than the diameter of a human hair. To minimize loss of signal power, this requires good mating of two fiber end-faces.

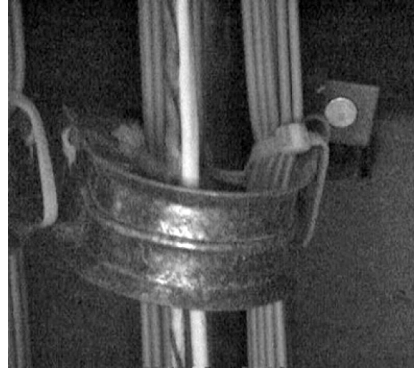


Figure 26 – Example of a common cause of a fiber failure

- **Contaminated fiber connections.** Leading cause of fiber failures results from poor connector hygiene. Dust, fingerprints, and other oily contamination cause excessive loss and permanent damage to connector end-faces.
- **Too many connections in a channel.** Simple, but it is important to consider the total allowable loss (per intended application standard) and typical loss for connector type during the design process. Even if the connectors are properly terminated, if there are too many in a channel, the loss may exceed specifications.
- **Misalignment.** The best way to achieve good fiber alignment is to fuse the two fibers together with a precision splicing machine. But for several practical reasons, connection of fibers is often done mechanically with fiber optic connectors. There are many commercially available connector types that all have their advantages and disadvantages. Typical loss specifications are a good proxy for how good they are able to align fibers. Any such specifications used for data communications should be compliant with FOCIS standards.
 - **Poor quality connectors or faulty termination.** Good quality connectors have very tight tolerances in order to maintain precise alignment
 - **End-face geometry.** Performance of fiber optic connectors is largely a function of the geometry of the end-face. This geometry can be measured in a laboratory with precision interferometry equipment. In the field, the following parameters are inferred in loss and reflectance measurements
- **Roughness.** Scratches, pits and chips produce excess loss and reflectance
- **Radius of curvature.** The convex surface of the connector should nicely mate up with another connector
- **Apex offset.** The core of the fiber should be centered near the highest point of the connector.
- **Fiber height.** A protruding (underpolished) fiber does not mate well and an undercut (overpolished) connector will perform poorly due to the presence of an air gap
 - **Unseated connectors.** A connector may be plugged into an adapter bulkhead but may not be seated and connected with its mate. Worn or damaged latching mechanisms on connectors or adapters are sometimes the culprit
 - **Poor cable management.** Strain on a connector may cause misalignment due to becoming partially retracted, broken, or unplugged

- **Polarity.** Perhaps the simplest fiber cabling fault is a reversal of transmit and receive fibers. This is usually easy to detect and repair. But sometimes connectors are duplexed together and must be broken apart to be reversed. Standards designate polarity with a labeling convention that is seldom taken advantage of, resulting in confusion.
 - Polarity should be designated with A and B labels or colored boots
 - A is for transmit and B is for receive; OR, red is for transmit and black is for receive

Poor cable management, system design, or damaged cable also causes faults in fiber cabling systems. Fiber has a very high tensile strength, but is susceptible to crushing and breaking if abused.

- **Bends.** Macro and microbending caused by tight cable ties or bend radius violations result in excessive and unexpected loss
- **Breaks.** Light will no longer propagate past a location where the glass is crushed or cracked in an optical fiber.
- **Intersymbol interference (ISI).** Disturbed Signal is a fault that is usually the result of poor system design. A system that is not certified with the application standard in mind is susceptible to ISI
 - Modal dispersion from violation of distance limitations on multimode fibers
 - Reflections from too many highly reflective connectors causing increased bit errors due to excessive return loss

Troubleshooting basics

- **Keep it clean.** Dirty connections are the worst cause of failing connections and testing challenges. Clean fibers each time they are connected. You can verify that fibers are clean by using an instrument such as a FiberInspector microscope to examine fiber end faces.
 - Dust blocks light transmission
 - Finger oil reduces light transmission
 - Dirt on fiber connectors spreads to other connections
 - Contaminated end-faces make testing difficult
 - Remember to inspect equipment ports, as these equipment ports (routers, switches, NICs) get dirty too
- **Use the correct test setup.** Test standard per specifications will ensure that you get the most accurate, consistent, understandable and repeatable results
- Use recommended fiber mandrels to improve loss measurement accuracy and repeatability.
- High quality TRCs and launch fibers should always be used; Use of random, questionable quality test cords should always be avoided.
 - All TRCs for loss testing should come with good test result data
 - Test cords should make polarity easy for you – Fluke Networks' cords feature red boots on the end at which light enters and black boots on the end at which light exits
 - Cords should be kept clean and replaced when they show signs of wear
- Choose test limits that are appropriate to both generic cabling standards and application standards

8. How to Troubleshoot Common Faults with an OTDR

OTDRs are the most powerful troubleshooting tool for fiber optic cabling. Smart use of an OTDR can eliminate time consuming trial and error troubleshooting.

Benefits of troubleshooting with an OTDR include:

- **Single ended testing.** no need place test equipment at both ends of a fiber optic link, making it easier for one technician to efficiently troubleshoot
- **Precise location of faults.** OTDRs can see the location of breaks, too tight bends, dirty connectors
- **Qualification of known events such connectors and splices with their locations** infer their associated loss and reflectance

Finding faults with an OTDR

1. Make sure that opto-electronics are not live on fiber links
2. Turn the OTDR on and plug a good quality, clean launch fiber (at least 100m) into OTDR port
3. Plug the launch fiber into one end of the channel (don't forget to clean the end-face before connecting to tester)

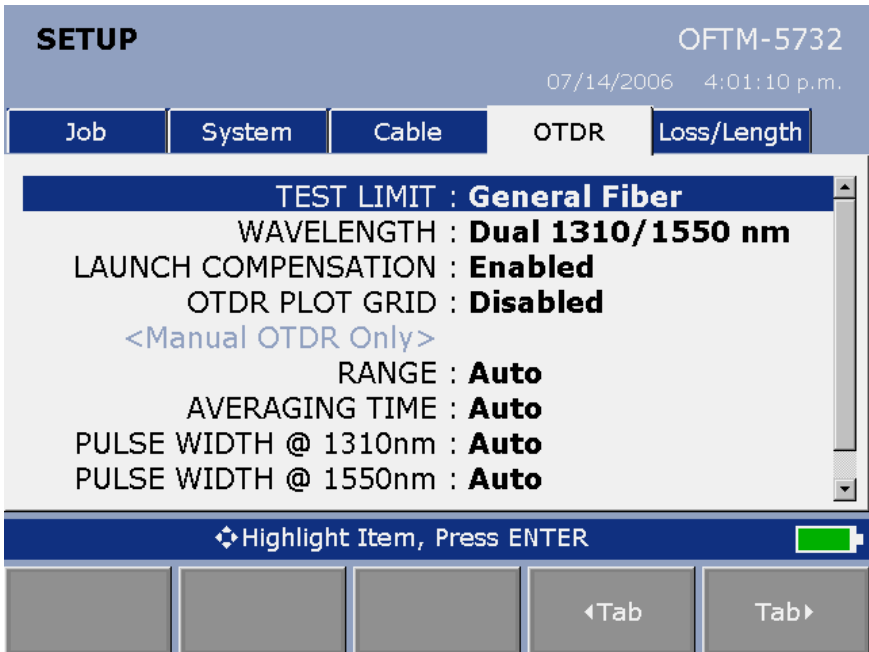


Figure 27

4. Set up the OTDR for testing
 - a. Choose the fiber type to be tested and/or characteristics from setup menu
 - b. Set a pass/fail limit of 0.3 dB for connectors and 0.1dB for splices
 - c. Choose 'Dual Wavelength Testing' from OTDR setup menu
 - d. Set launch fiber compensation to simplify your testing by setting the end of your launch fiber as the starting point (zero feet/meters) on the trace
 - e. Check to make sure that pulsewidths, averaging time, distance range are set to 'Automatic Mode'
 - f. Set loss threshold to 0.01dB and choose 'Dual Wavelength Testing'
5. Run 'Channelmap' to make sure that the link looks like what you believe you are plugged into

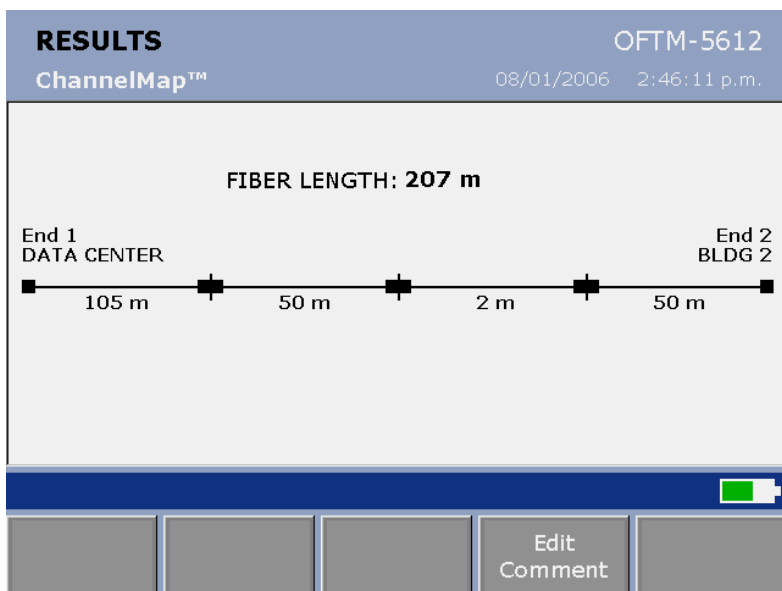


Figure 27a

- a. If you cannot see past the end of your launch fiber, the problem is that the connector is not fully seated in the back of the patch panel
 - b. You should see all connectors and cabling segments that you expected to see. If not, you have a break or an unplugged cable
6. An advanced feature on the OptiFiber OTDR is 'Faultmap' (**Figure 27b**). 'Faultmap' uses the event analyzer to determine the quality of each connection without any user setup or programming. If 'Faultmap' identifies a connector as questionable, further analysis is warranted to ensure acceptable connector performance.

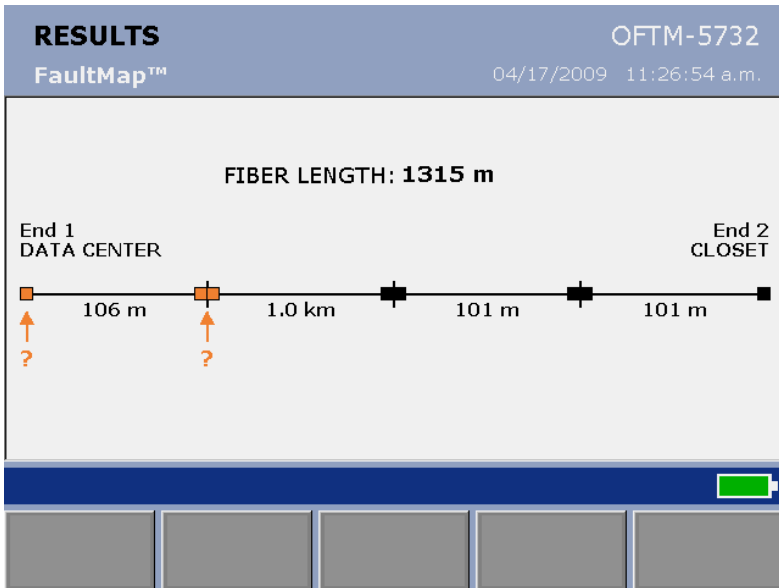


Figure 27b

7. Now you should change to 'Autotest' and shoot a trace
 - i. If the display says that you failed the test, look at the trace or event table to identify where the failing event is to locate and identify the failure.

EVENT TABLE				OFTM-5612
Auto OTDR				06/22/2006 6:29:15 p.m.
LOCATION (m)	dB@850nm	dB@1300nm	EVENT TYPE	STATUS
0.00	N/A	N/A	OTDR PORT	
102.14	0.39	-0.22	GHOST SOURCE	PASS
152.72	0.20	0.97	REFLECTION	FAIL
164.11	1.17		LOSS	FAIL
174.58	0.19	0.65	REFLECTION	PASS
204.69	0.00	0.05	GHOST	
226.32	N/A	N/A	END	

◆ Scroll List, ◆ Select Field, Press EXIT to view SUMMARY

View Trace Sort Field View Details

Figure 27c – Event Table on Fluke Networks' OptiFiber OTDR

- ii. If the end of the fiber is much closer that it should be, you have a broken fiber at that location
- iii. You may use a visual fault locator or create a macrobend with a real time trace running to physically locate the break or failing event

- iv. Press 'Next Trace' to see the same fiber at a longer wavelength. This will often magnify poor events, as longer wavelengths are more susceptible to certain types of losses
 - v. If you have connectors that fail limits and have long sweeping tailing on the trace, you probably have dirty connectors. You may use a FiberInspector to physically inspect each connector. Make sure to have a good cleaning kit with you!
- b. Once you clean and repair any faults, retest the link.
- i. If it now passes your test limits, save the results and export them to LinkWare for record keeping. If you have the FiberInspector option, you can also save your clean fiber end-face images to the same report!

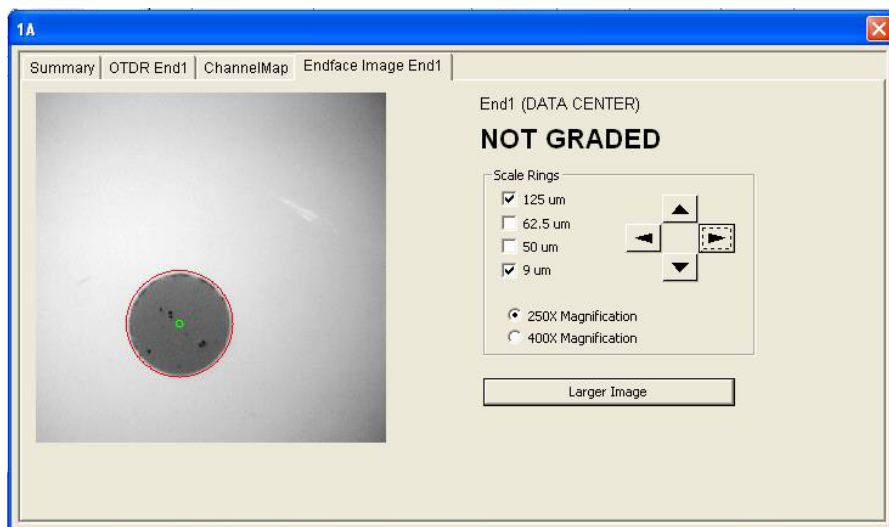


Figure 27d

- ii. If you would like to do a before and after comparison, you can use 'Trace Overlay' to display

Note that with some basic testing knowledge, efficient first-line troubleshooting can also be done with an LSPM kit. For example, basic polarity verification can be conducted using the SimpliFiber Pro Fiber Test Kit's 'FindFiber' feature. This same capability can also greatly simplify the normally time-consuming and personnel-intensive project of cable identification between patch panels. Using FindFiber Remote ID sources, a single technician can complete end-to-end testing by plugging them into the port(s) to be tested before checking the ports on the distant end with the SimpliFiber Pro power meter to read the unique identifying signals transmitted by the FindFiber sources.

As an instrument that tests from one end of a fiber plant to the other, the LSPM can also be used to narrow down any questionable connections. By leaving a light source at one end, a technician can systematically disassemble a link by disconnecting each component at the connectors to inspect and clean the fiber end-face before testing the plant up until that point. If the loss measurement is within expectations, you can reconnect (after inspecting and cleaning the end-face of the link to be mated, of course) and repeat at the next connection down the line until the problem point is identified and corrected.

Detecting intermittent power fluctuations is also a common issue where an LSPM can troubleshoot. Whether it is a faulty switch or a shoddy connection into the back end of a connector, power fluctuations are problematic but difficult to detect and capture because they are so fleeting. However, the 'Min/Max' feature on the SimpliFiber Pro power meter helps you to ensure that transmission is stable over a link by automating the precision tracking of its power level. By providing the upper and lower bounds of a wavelength measurement throughout the duration of a testing session, you attain better visibility into where any trouble points may be.

9. End-Face Inspection and Cleaning Inspection

Proper inspection helps in detecting two of the most common (yet easiest to prevent) causes of failure: damaged and dirty fiber end-faces.

Damage occurs in the form of chips, scratches, cracks, and pits to the core or cladding and can result from mating contaminated end-faces. Tiny foreign debris left on the core can also damage end-faces during the mating process as they are connected together.

Sources of contamination are everywhere, whether it be from a touch of a finger or the brush of a clothing fabric, much less the omnipresent dust or static-charged particles in the air. Ports are also subject to the same contamination but are often overlooked. Mating a clean connector to a dirty port not only contaminates the previously clean connector but can also cause fiber damage or failure. Even the protective coverings or “dust caps” on straight-from-the-package connectors and assemblies can cause contamination due to the nature of the production process and materials.

The typical assumption is that a quick visual check of the end-faces is sufficient to verify cleanliness. As mentioned previously, the cores of these fibers are extremely small – ranging from roughly 9 to 62.5µm. Put into perspective, with a diameter of 90µm, the average human hair is anywhere from 1.5 to 9 times larger! With such a tiny core size, it is impossible for any end-face defects to be spotted without the aid of a microscope.

There are two types of fiber inspection microscopes:

- **Optical (Figure 28)** – tube-shaped and compact, signals transmitted by the FindFiber sources. you to inspect the end-faces directly. Popular because they are inexpensive; however, they are not able to view end-faces inside equipment or through bulkheads.
- **Video (Figure 29)** – small optical probe is connected to a handheld display. The probe size makes them excellent for examining ports that are in hard-to-reach places; large displays enable easy identification of end-face defects. They are also safer as they show an image and not the actual end-face being observed, reducing the risk of exposing one’s eye to harmful radiation.

Within the context of inspecting fiber optics – showing the user what the naked eye cannot see, the primary desired attribute is detection capability – basically the smallest-sized object that it can detect.



Figure 28 –
Optical microscope

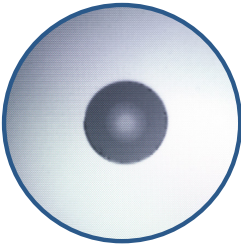


Figure 29 –
Video microscope

Cleaning

Properly cleaned end-faces can actually “add” up to 1.39 dB onto your loss allowance. **(Figure 30)**. In other words, if you have a fiber plant with an overall loss of 5.0 dB against a specified budget of 4.5 dB, cleaning any dirty end-faces may help to drop the link loss down to just above 3.6 dB, providing a “Pass” and plenty of head-space. Consequently, it is important to choose your cleaning tools and methods wisely while avoiding commonly-practiced bad habits. Perhaps the most typical mistake is using canned air to blast fiber connectors or ports. While helpful for displacing large dust particles, it is ineffective on oils, residues, or tiny static-charged particles that are equally detrimental in causing failures.

Clean fiber end-face



Contaminated fiber end-face

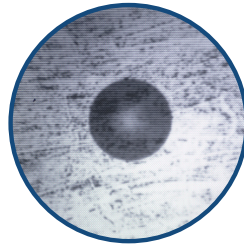


Figure 30 – Comparison between a clean and dirty fiber end-face

The same problem occurs when using shirt sleeves or “clean” cloths to wipe connectors; in fact, the trace amounts of lint and dust-attracting static from using such materials will likely add to the contamination rather than reduce it. Even isopropyl alcohol (IPA), which has historically been viewed as an acceptable solvent, is proving to be inferior to specially formulated solutions. IPA’s inability to dissolve non-ionic compounds such as pulling lube and buffer gel, and its residue-leaving evaporation process make engineered solvents the superior choice. When using these solvents, the proper cleaning order is “wet to dry” using clean, lint-free wipes **(Figure 31)**.



Figure 31 – “Wet to dry” cleaning methodology. Apply a small spot of solvent to the starting edge of a wipe. Holding the end-face connector perpendicularly, swipe the end-face from the wet spot to the dry zone.

The types of cleaning resources vary in complexity and price, ranging from simple wipes to devices that incorporate ultrasound with water. Which tool you use will be dependent upon need and budget – but for the majority of the cabling jobs and projects, the pairing of lint-free wipes and swabs with engineered solvents now found in fiber inspection, certification, and cleaning kits will be sufficient.

10. Conclusion

Cabling installation is a multi-step process. It is a prudent practice to certify the cabling system after installation to ensure that all installed links meet their expected level of performance. Certification will likely identify some failing or marginally passing results. In order to deliver a high quality cabling system, the defects that cause the failures and marginal passes must be uncovered and corrected.

Fluke Networks' full suite of fiber certification instruments (Appendix 2) have a an unparalleled history of providing unique and powerful diagnostics assistance to installation technicians. By knowing the nature of typical faults and how the tester's diagnostics report them, you can significantly reduce the time to correct an anomaly, an installation error, or a defective component. Personnel responsible for the network's operation can also benefit from the diagnostic capabilities of a certification test tool; with the tester's assistance, they can limit the duration of network downtime and restore service quickly.

We highly recommend that you thoroughly familiarize yourself with the capabilities of your test tool – it is truly a modest investment that pays for itself many times over. In addition to your precision instrument, Fluke Networks also provides a wide variety of expert and timely support options. Whether you are an installer, network owner, or contractor, the following resources are available:

- **White papers and Knowledge Base articles** – insightful studies and helpful advice on relevant structured cabling topics
- **Unsurpassed technical assistance** from the highly trained Fluke Networks Technical Assistance Center (TAC)
- **Certified Test Technician Training (CCTT) classes** available around the world
- **Gold Support program** – comprehensive maintenance and support including priority repair with loaner, annual
- calibration and priority TAC support with after hours and weekend coverage

11. Glossary

Certification testing – the process of testing the transmission performance of an installed cabling system to a specified standard; requires an OLTS for “Tier 1” certification and an OTDR for “Tier 2” certification

Channel – end to end transmission medium between a transmitter and receiver dB – logarithmic unit of measurement used to express magnitude of power relative to a specific or implied reference level; usually associated with loss

dBm – power level expressed as the logarithm of the ratio relative to one milliwatt

FiberInspector – Fluke Networks’ popular line of handheld fiber end-face and bulkhead port inspection instruments, ranging from tube to video microscopes

Gbps – gigabits per second

Launch cord fiber – length of fiber placed between the link segment under test and the OTDR to improve the OTDR’s ability to grade the near-end connector and any abnormalities in the first connection

LED – Light Emitting Diode, a relatively low-intensity light source

Link – the physical cabling for a transmission

Mbps – megabits per second

OLTS – Optical Loss Test Set, a baseline “Tier 1” certification instrument that measures the loss of a link over its length

LSPM – Light Source Power Meter, basic fiber verification instrument composed of a power meter and a source to measure loss over a link

TRC – Test Reference Cord, a high-quality fiber cord between 1 to 3 meters long with high performance connectors, ideally with end-faces with special scratch resistant hardened surfaces that enable numerous insertions without degradation in loss performance

VCSEL – Vertical Cavity Surface Emitting Laser, commonly used in multimode light sources

Verification testing – the process of testing the transmission performance of an installed cabling system to ensure that it meets a minimum threshold

VFL – Visual Fault Locator, optical source that transmits a low-powered laser to identify breaks in fiber links

Appendix 1 – Fluke Networks Fiber Test and

Verification			Verify loss over entire link to ensure loss budget not exceeded
	Check connectivity	Check polarity	
Specialized Fiber Cleaning Supplies 			
VisiFault VFL 			
FindFiber Remote ID 	✓	✓	
SimpliFiber Pro Optical Loss Test Kit 	✓	✓	✓
CertiFiber OLTS 			✓
FiberInspector Video Microscope 			
DTX Series with Fiber Module 			
DTX Compact OTDR 			
OptiFiber OTDR 			

Troubleshooting Instruments

Troubleshooting		Certification		
Check for fiber end-face contamination* or damage	Clean contamination	Find faults	Basic (Tier 1)	Extended (Tier 2)
	✓			
		✓		
✓			✓	
✓				
			✓	
				✓
✓		✓		✓

Appendix 2 – Test Reference Methods

We reviewed the theory of the link loss test for optical fiber links in ‘Process and Equipment Requirements’ under the ‘Cabling Certification’ section of Chapter 3, ‘Testing Theory – Performance of Optical Fiber Cabling.’ The loss measurement of an installed optical fiber link is derived from two power measurements. The “test reference measurement” establishes the “no loss” power level against which the test tool compares the power through the link under test. The difference between these two power levels yields the loss of the link under test. We have pointed out that it is critically important that the loss measurement is executed with the same source and light launch conditions as used in the reference measurement.

Many standards recommend the one-jumper test reference measurement for premises wiring cabling. Relatively short lengths and multiple connections characterize enterprise-cabling systems within a building or campus. Access or long haul optical fiber links may only have one connector at either end of the link which can be hundreds of times longer than the longer enterprise cabling links. It is very important that the test of an enterprise cabling system correctly and accurately accounts for the loss contribution of every connections. The evaluation of the different methods for setting the test reference evolve in the first instance around the way these methods account for the two end connectors of the link segment under test. Each of the test reference methods we will review treat any connection or splice between the end connections of the link under test in the same way. **Table 2** demonstrates that for a simple segment of 300 m with one end connection at either end, the loss allowance in these end connections represents 1.5 db out of a budget (maximum loss limit) of 2.55 dB. This is 59% of the link loss budget.

The one-jumper method

Refer back to the explanations of **Figure 13** and **Figure 14**. The losses in each of the two end connections of the link under test are completely and accurately included. The critique of the one-jumper method is two fold:

- a. The connectors in the test tool must match the connectors at the end of the link under test
- b. A second test reference cord must be added to connect the power meter to the far end of the link; its quality and performance may be unknown.

Fluke Networks has dealt with this critique in a number of ways.

1. The DTX Series fiber test modules as well as other LSPM test tools of recent vintage such as the SimpliFiber Pro offer replaceable adapters for the power meter. The testers typically include as standard equipment the SC connector with optional adapters and test reference cords available to test ST, LC or FC connector systems with the preferred one-jumper test method.

2. All TRCs are manufactured to the same exacting specifications with end faces that have been hardened using a patented method to provide scratch resistant and durable cords with an optimum geometry for light coupling. The overall loss limits for these TRCs is 0.1 dB.

In the case of the DTX Series fiber test modules, the TRCs are implemented as duplex cords. The added TRC is therefore attached and is of equal quality and performance as the cord used to set the reference. The fact that the added TRC is attached assures that a high quality cord is readily available to the test technicians in the field.

Of course, there are connector systems for which the one-jumper test reference method cannot be adopted. The most prevalent example is the MT-RJ connector type. We will first explain the two-jumper method and follow that section with an adaptation of the two-jumper method which we will call the “modified one-jumper method” because it meets the requirement to properly and accurately account for the losses in the end connections of the link segment under test.

The two-jumper method

Figure A3-1 demonstrates the connections for the two-jumper reference measurement. The power meter is connected to the test reference cord TRC1 while the power meter is connected to a similar test reference cord TRC2. For the reference measurement, the two TRCs are connected with the appropriate reference adapter (CR1). We recommend to use adapters manufactured for singlemode applications since these adapters are manufactured to more exacting mechanical specifications that ensure better and more repeatable alignment of the fiber cores.

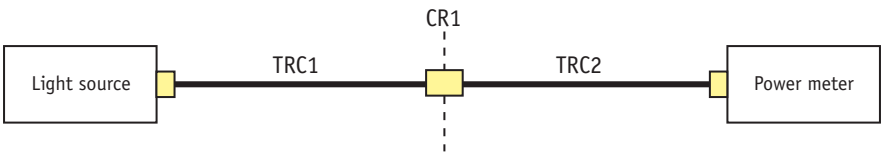


Figure A3-1 Two-jumper reference method – The optical loss reference measurement captures the loss in the connection of Test Reference Cord 1 (TRC1) and the Light Source, the loss in TRC1, the loss of the reference connection CR1, the loss in TRC2 and the loss in the connection between TRC2 and the power meter.

We will repeat the analysis of the reference power measurement as we did in our analysis of the one-jumper reference measurement illustrated in **Figure 13**. It is worthwhile to emphasize once more the importance of the launch conditions from the light source into TRC1. We have not shown the mandrel but the installation and use of the proper mandrel is mandatory to obtain reliable and repeatable test results. Our analysis follows the light path from the light source to the power meter.

The coupling of light energy from the light source into TRC1 will be affected by the status of the connection between the test instrument and TRC1. This does not need to be perfect

and its condition does not have to be known in detail as long as it remains stable for the duration of the test. Therefore, do not modify in any way the connection between TRC1 and the light source. A minor loss occurs in each of the short TRCs; recall that the typical loss for the 850 nm wavelength is about 0.0035 dB per meter. For the 1300 nm wavelength, this loss is 0.0015 dB. Assuming we will not abuse the TRCs, the loss in the fiber do not change while we test the links in the network. A loss occurs in the adapter CR1 between the two test reference cords. We will discuss its influence in a moment. There is also some loss in the coupling of TRC2 into the power meter. Using this method, we will not have to touch this coupling as we connect to the link segment under test. Look ahead at **Figure A-2** which shows the test connections for the link segment loss test.

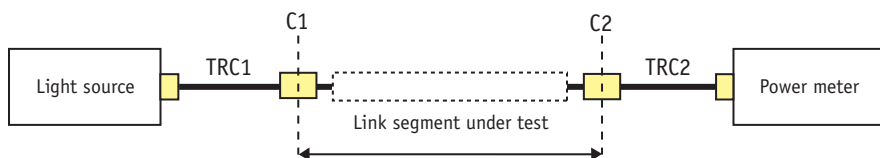


Figure A3-2 Two-jumper method optical loss measurement – The “difference” between the reference power level and the loss test power level is the power loss in the link under test, loss in connection C2 and the difference in the loss between CR1 (reference connection) and C1. This difference can vary; the total loss in connection C1 is not included in the link loss test result.

We will now examine the difference in the light loss between the reference measurement and the link measurement to ensure that this difference accurately represents the loss in the link segment under test. The difference fully covers the link segment under test and connection C2 but not C1. The reference measurement includes the loss of the connector CR1. During the link measurement, we measure the difference between the reference connection CR1 and connection C1. This difference does not equal the loss in connection C1. This difference cannot be known or predicted. The two-jumper loss measurement method does not fully evaluate the link segment and both of the connections at its ends.

If you are testing against an application standard, the result is likely low with 0.5 dB – more or less. This is not acceptable when loss limits are in the 2.6 to 3.5 dB range. A 0.5 dB error represents an error of 25% or 14%.

If you had selected an installation test standard, this method can somewhat be adjusted by ensuring that you exclude the C1 connection from the count of connections in the link. The test limit calculation then excludes the loss allocated to one connection. We said ‘somewhat’ because the advantage of the LSPM loss measurement rests on the fact that the contribution of each element is accurately counted.

The “modified one-jumper” method

We can adjust for the error in the two-jumper method by adding a TRC when measuring the link loss as shown by TRC 3 in **Figure A3-4**. The reference measurement for this method is identical to the method for the two-jumper method we just reviewed as is shown in **Figure A3-3**.

We have colored the connections in **Figure A3-3** and **A3-4** to show that the connectors in the test tools and those at the end of the link under test do not need to be the same type. Fluke Networks recommends this method for a connector type like the MT-RJ for which the “true” one-jumper method cannot be used. These TRCs are hybrid cords which means that they are terminated with different connectors at either end. TRC3 for the MT-RJ application must have alignment pins installed to properly mate with the two standard connections. An MT-RJ TRC kit is available from Fluke Networks. Recall that removable adapters at the power meter offer the preferred method to use the true one-jumper method when this alternative is available.

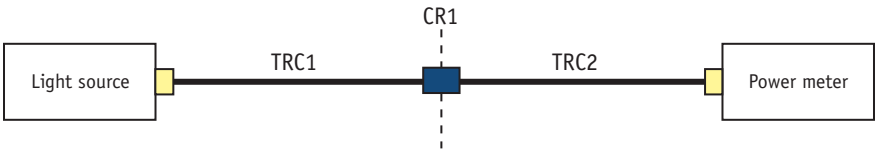


Figure A3-3 – The “modified one-jumper” reference method uses the exact same reference method as the two-jumper reference method. Note that the TRCs are hybrid cords terminated at one end with a connector matching the test equipment and at the other end with a connector that matches the link under test. The figure highlights the different connector types by using different colors.

The analysis of the losses through the configuration shown in **Figure A-4** shows that the loss in connection C1 is fully accounted for, as well as the loss in the link under test and in connection C2. We also measure the loss in TRC3 – the added TRC – and the difference of the loss between connections CR1 and CR2. The loss in the one-meter TRC3 is small (with 850 nm light this loss is 0.0035 dB). The difference between the two reference connections is less than 0.05 dB – half of the total loss specification for reference cords. The error observed or measurement uncertainty of the two-jumper method has approximately been reduced to 1/10th using the “modified one-jumper” method.

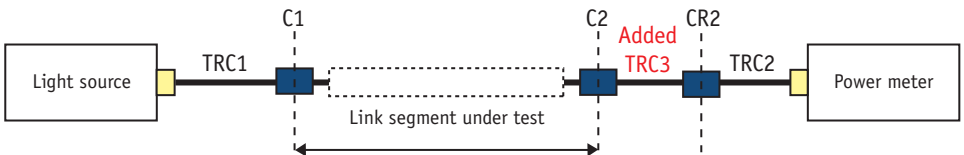


Figure A3-4 – The “Modified One-jumper” method optical loss measurement – The “difference” between the reference power level and the loss test power level is the power loss in the link under test, connections C1 and C2, the added TRC3 and the difference between the loss in CR1 and in CR2 (two reference connections).

The three-jumper method

ISO/IEC standard 147363-3 emphasizes the three-jumper method as a generic method that can be applied regardless of the type of connectors used at the ends of the link under test or in the test equipment. **Figure A3-5** shows the reference connection. As the name of this method implies, you use three TRCs to make the connection for the reference measurement. Then you remove the middle TRC (TRC3 in **Figure A3-5**) and “replace” this TRC with

the link under test as shown in **Figure A3-6**. “Replace” means that the light source with TRC1 attached moves to one end of the link segment under test and the power meter with TRC2 attached moves to the opposite end of the link segment under test.

The optical loss reference measurement captures the loss in the connection of Test Reference Cord 1 (TRC1) and the Light Source, the loss in TRC1, TRC2, TRC3, the loss of the reference connections CR1, CR2 and the loss in the connection between TRC2 and the Power Meter.

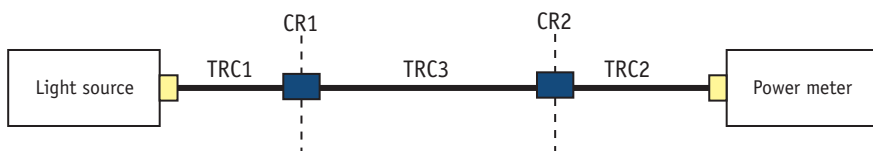


Figure A3-5 – Three-jumper reference method – The optical loss reference measurement captures the loss in the connection of Test Reference Cord 1 (TRC1) and the Light Source, the loss in TRC1, TRC2, TRC3, the loss of the reference connections CR1, CR2 and the loss in the connection between TRC2 and the Power Meter

The analysis of the losses for the link measurement shown in **Figure A3-6** shows that the losses in the link under test are fully included but that we are measuring the difference in the loss between CR1 and C1 and the difference between C2 and CR2 rather than the full losses in C1 and C2. The loss inside the link segment under test consists of the sum of the loss in fiber, internal connections, and splices if present. The full loss in neither of the end connections of the link under test is included in the measurement results.

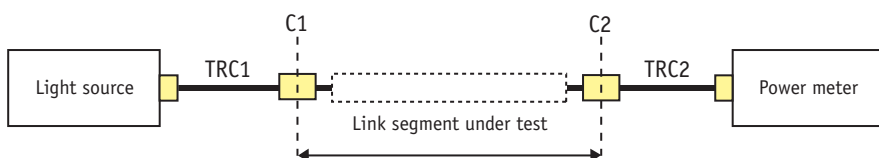


Figure A3-6 – Three-jumper method optical loss measurement – The “difference” between the reference power level and the loss test power level is the power loss in the link under test and the difference in the power losses between the reference connection CR1 and connection C1 and between the reference connection CR2 and C2. The actual loss in connections C1 and C2 is not included in the link loss test result.

The IEC 147363-3 document specifies the following formula to calculate the pass or fail outcome of this loss test:

$$\text{Link Loss} = (\text{Loss in segment under test}) + \text{Loss (C1-CR1)} + \text{Loss (C2-CR2)} \quad (\text{A3-1})$$

If the loss in CR1 and CR2 were zero, this formula would yield the desired results:

$$\text{Link Loss} = (\text{Loss in segment under test}) + \text{Loss (in C1)} + \text{Loss (in C2)}.$$

The standard also defines the allowable loss limits for “test connectors” which we refer to as “reference connectors” in this document – see **Table A3-1**.

	Reference connector limit	Test limit for connectors mated with a reference connector
Multimode	0.1 dB	0.3 dB
Singlemode	0.2 dB	0.5 dB

Table A3-1 Definition of maximum insertion loss of connections with reference connectors as specified in IEC 14763-3

When we insert the values in table A3-1 for multimode into formula (A3-1) above, we obtain:

$$\text{Link Loss} = (\text{Loss in segment under test}) + (0.3 - 0.1) + (0.3 - 0.1), \text{ or}$$

$$\text{Link Loss} = (\text{Loss in segment under test}) + 0.4$$

In conclusion, the standard uses a “correction factor” of 0.4 dB to account for the fact that the actual losses in the end connections of the link under test are not measured by the three-jumper method. The quality of the TRC cords is critical:

- Testing with cords that are worse provide a more lenient limit
- Testing with cords that are better provide a tougher limit
- This is counter-intuitive but creates a real problem

DTX customers can measure the patch cord loss but this additional step represents a huge inconvenience for the contractor and we are guessing that this additional step will not be done in the field. Now, you probably understand why Fluke Networks does not recommend this method if the job can be performed using a method with less uncertainty (which equals more accuracy), and advocates the one-jumper method.

Your authorized Fluke Networks distributor

NETWORK SUPERVISION

Fluke Networks, Inc.

P.O. Box 777, Everett, WA USA 98206-0777
(800) 283-5853 Fax (425) 446-5043

Western Europe

00800 632 632 00, +44 1923 281 300
Fax 00800 225 536 38, +44 1923 281 301
Email: info-eu@flukenetworks.com

Canada (800) 363-5853 Fax (905) 890-6866

EEMEA +31 (0)40 267 5119

Fax +31 (0)40 267 5180

Other countries call (425) 446-4519

Fax (425) 446-5043

E-mail: fluke-assist@flukenetworks.com

Web access: <http://www.flukenetworks.com>

©2009 Fluke Corporation. All rights reserved.
Printed in U.S.A. 5/2009 3473059 Rev. A